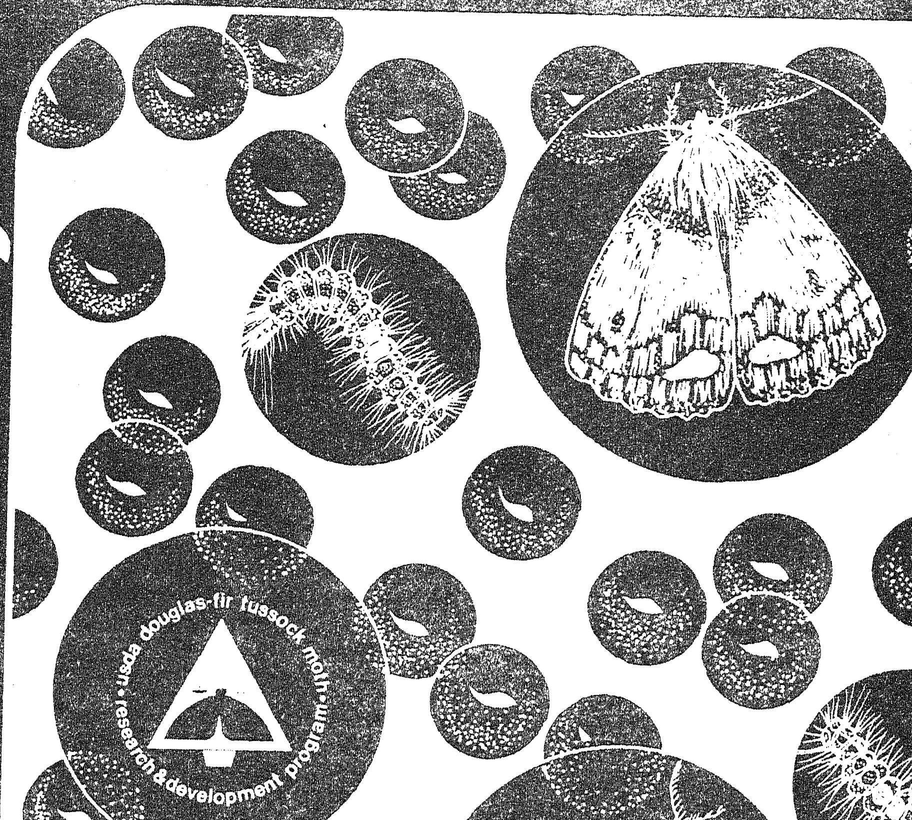
NERAL TECHNICAL REPO

Documentation of the Douglas-Fir Tussock


usda douglas-fir tussock moth research & development program

Reference Abstract

Documentation of three model versions: the Douglas-fir tussock
th population-branch model on (1) daily temporal resolution, (2) inst
mporal resolution, and (3) the Douglas-fir tussock moth stand-outbrea
del; the hierarchical framework and the conceptual paradigm used are
scribed. The coupling of the model with a normal-stand model is dis-
ssed. The modeling convention and algorithm used are also discussed

YWORDS: Population dynamics, defoliation damage, outbreak predictio
models, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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INTRODUCTION

This paper documents the mathematical form and computatio of the Douglas-fir tussock moth (DFTM) stand-outbreak model. is constructed to simulate outbreaks of Douglas-fir tussock mo *pseudotsugata* (McDunnough)), a defoliator of Douglas-fir (*Pseu menziesii* var. *glauca* (Beissn.) Franco), and the true firs (*Ab* in western North America. The details of the model's backgrou historical development, and the basis for formulation of its p structure and functional forms will be covered in another pape documentation of model behavior.

The conceptual structure of the DFTM model provides a pers on the relation of the various models developed. Three versio DFTM outbreak-population model were developed. Version 1.2, p here, is at daily resolution and differs little from the origi (V1.1) conceived in 1974. The second version presented (V2.2) originally developed (V2.1) to reduce computing costs and nece only minor alterations. These two versions follow the insect branch through 1 year. This branch model became the operationa the stand-outbreak model (V3.1). Details of the coupling rela between the normal-stand model and the DFTM stand-outbreak mode the overview of the general model structure.

A summary of the FLEX processing algorithm and notational precedes detailed documentation of the models. Adjustments to current algorithm were necessitated by the DFTM stand-outbreak structure, and these are detailed next. The computational fra which the models are embedded is discussed in these two sectio

A short discussion, preceding the details of each model v gives the relations among the three model versions and how the from each other. The detailed FLEXFORMS, summarizing model st and parameterization, follow.[1] Next are the specifics of fil used in the third model version. This includes a more detaile of the computational order discussed in general in another sec

Last is a description of the stand-postoutbreak model. T the filtering mechanism that assigns mortality and growth impa stand of trees. These result from defoliation of the model br transformed by the whole-tree-defoliation equation.

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[1]

A hierarchical structure is conceptualized for the general model: ach level is a dynamic unit of the level above (figures 1 and 2).

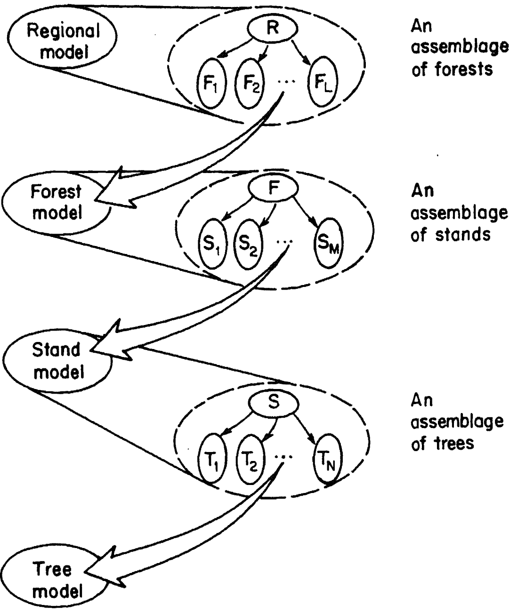


Figure 1.--How various models assemble into the hierarchical model. A region (R) consists of a number (L) of forests (F), a forest consists of a number (M) of stands (S), and each stand consists of a number (N) of trees (T).

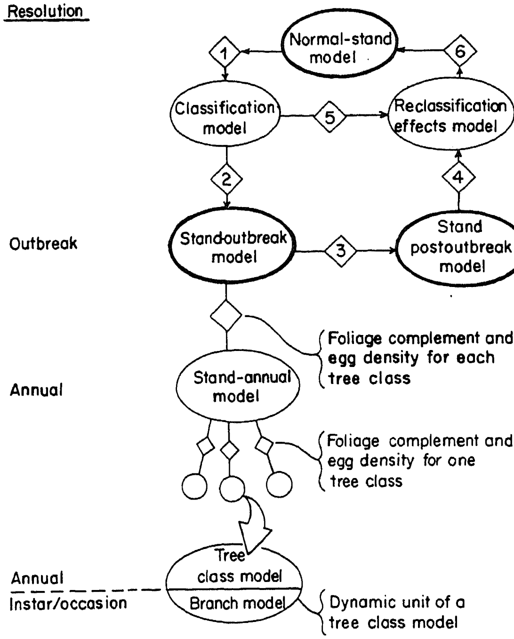


Figure 2.--Hierarchical organization of the DFTM stand-outbreak model relative to the normal-stand model.

A. Regional model: The socioeconomic context of the forest.
Resolution: 1 century; not implemented.

B. Forest model: An explicit assemblage of ecotype-stand units.
Resolution: 1 rotation; not implemented.

C. Stand model:
(a) Normal-stand model: An assemblage of trees of varying size and species, in a specific ecological and management regime.
Resolution: 1 decade; not implemented.
(b) Stand-outbreak model: An assemblage of tree classes prescribed by the effective resolution of knowledge of stand conditions and insect population levels. The conceptual structure of an outbreak is patterned after the observed sequence of population "phases" of Wickman et al. (1973). Th successive years of an outbreak are parameterized according t phase-specific mortality vectors and other population propert
Resolution: Duration of outbreak, 4 years.

defoliation into mortality, top-kill, and reduction of
for each tree class and covers delayed mortality and r
management practices.
Resolution: Duration of postoutbreak period, 6 years.

(d) Stand-annual model: The potential of integration
tree classes at the end of each year effectively impos
stand-annual structure on the assemblage of tree class
Redistribution of eggs over the tree classes in the st
determined in this model.
Resolution: 1 year.

D. Tree model:

(a) Normal-tree model: The rules of normal growth an
survival of a tree, of specific species, size, and age
of specific ecological and stand regimes.
Resolution: 1 year; not implemented.

(b) Tree-class model: A class of trees is represente
typical tree. Defoliation of the typical tree over a
is derived from the branch model.
Resolution: 1 year.

(c) Tree-outbreak model: Normal growth increments an
survival are modified by the degree of defoliation as
mined from the branch model. The tree-outbreak model
simply a branch model, coupled or linked over seasons,
outputs translated at the end of the outbreak into the
of defoliation on tree mortality, top-kill, and growth
model does not explicitly appear, being subsumed by th
outbreak model. Effects of defoliation are relegated
stand-postoutbreak model.
Resolution: Duration of outbreak and postoutbreak per

E. Branch model: Contains the rules of growth and surviv
tussock moth, branch defoliation, and the production c
foliage and loss of old foliage by the branch; specifi
ratio of eggs to foliage, for nominal ratio of new to
foliage, and for species of tree and year (phase) of c
Standardization of the total biomass of foliage on the
branch (100 grams for Douglas-fir and 144 grams for gr
(*Abies grandis* (Dougl.) Lindl.) allows specification c
two variables, percent new foliage and eggs (per total
of foliage).

The mechanisms of the branch model are conceptual
a daily resolution, with runs spanning one season. In
conditions for a season run are identifiable from the
nating condition of a season run which provides the ca
to couple several seasons (years) together. In the da
resolution branch model, days are occasions.

[2/] The postoutbreak period has been set at 6 years so that the ou
postoutbreak periods will sum to the resolution of the normal-stand m

For efficiency in computing, the daily resolution model was collapsed into an instar resolution model. This changes little and reduces the number of occasions in a season.

We can now identify several levels of temporal resolution: outbreak aining several phase-specific years), year (containing several ions), and occasion.

IDENTIFICATION OF COUPLING VARIABLES

In this outline of the couplings between the different models, c numerals correspond to those in the numbered diamonds in figure 2.

Outputs of the normal-stand model and inputs to the classification model: Those state variables and parameters of the normal-stand model needed to assign trees of the stand to the classes of the stand-outbreak model.

Outputs of the classification model and inputs to the stand-outbreak nodel:
i. The number of tree classes in the stand;
ii. For each tree class, represented by a "typical tree":
    a. The number of trees in the class;
    b. The foliage composition of the model branch: Biomass of foliage and percent new foliage;
    c. Egg density;
    d. Species;
    e. The weighting factor to account for relative contribution of a tree in the class to stand foliage biomass and insect population density;
iii. Ecological or site-specific model parameters.

Outputs of the stand-outbreak model and inputs to the stand-postoutbr nodel for each class of trees in the stand:
i. Defoliation of the model branch after each season during the outbreak;
ii. Tree defoliation at the end of the outbreak.

Outputs of the stand-postoutbreak model and inputs to the reclassification-effects model, for each tree class:
i. Direct mortality; proportion of trees that die as a direct result of defoliation;
ii. Secondary mortality; proportion of trees that suffer secondary mortality in the postoutbreak period, identified as:
    a. Bark beetle mortality;
    b. Other mortality caused by the outbreak;
    c. Noncausal mortality;
iii. Top-kill; proportion of trees in each top-kill subclass. Each subclass is defined in terms of height reduction. An additional output, the proportion of the nominal diameter-growth increment actually achieved is also given;

nor mortality, and for these trees, the damage expressed as

a. Proportion of the nominal height-growth increment actua achieved;

b. Proportion of the nominal diameter-growth increment actually achieved;

v. Factors for delayed reduction of growth beyond the postoutbr period.

. Outputs of the classification model and inputs to the reclassification-effects model: The record of which trees were assigned the various classes.

. Outputs of the reclassification-effects model and inputs to the normal-stand model: The allocation of mortality factors to the trees of the stand and the updating of growth increments to cove the outbreak period.

ABSTRACT OF THE FLEX CONVENTION AND ALGORITH

The conceptual basis of FLEX is the identification of several ki f variables and functions in the context of a general algorithm for ynamic behavior. Identify:

$\underset{\sim}{x}$, the vector of state variables;

$\underset{\sim}{y}$, the vector of output variables (functions of state var

$\underset{\sim}{z}$, the vector of input variables;

$\underset{\sim}{b}$, $\underset{\sim}{r}$, two vectors of constants (model parameters).

he update algorithm is a simple difference equation

$$\underset{\sim}{x}(k+1) = \underset{\sim}{x}(k) + \underset{\sim}{\Delta}(k)$$

ith $\Delta(k)$ constructed as a sum of internal variables that are identi s f function values. These functions account for fluxes (flows) bet tate variables. Flux from x_i to x_j is f_{ij};

$$f_{ij} = f_{ij}(k,\underset{\sim}{z},\underset{\sim}{x},\underset{\sim}{g},\underset{\sim}{s},\underset{\sim}{b},\underset{\sim}{r});$$

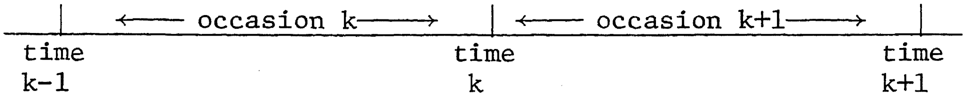
here g and s are vectors of functions; f_{ii} is a source or sink for epending on the sign of f_{ii}. The g functions are intermediate functi nternal variables that are used extensively,

$$g_i = g_i(k,z,x,b,r).$$

he s functions, or special functions, are included for further modeli nd programing flexibility; these are implemented as FORTRAN[3/] subrout nd are therefore much more general. Details of how this process is mplemented are given in the FLEX users' manual (White and Overton 977).

[3/] FORmula TRANslating system--a language used to express computer pro y arithmetic or logical formula.

and from this point forward uses the values of the variables at time
to compute the values of the state variables at time k+1. The proces
uses the values for time k to compute the outputs for time k+1. This
accounts for actions taking place during occasion k+1.



In a terminal (or FLEX) module the algorithm may be summarized a
follows:

(1) Receive (or calculate) inputs and store the values of $\underset{\sim}{z}$ using the z functions.
(2) Calculate and store the values of the g functions.
(3) Calculate and store the values of the f functions.
(4) Construct the update vector, $\underset{\sim}{\Delta}$.
(5) Update the state variables.
(6) Calculate and store (generate outputs) and values of $\underset{\sim}{y}$ usin
the y functions.

A time step k may be subdivided into q subintervals indexed by k' = 0
1, ..., q - 1. Then define:

$$\underset{\sim}{x}(k) = \underset{\sim}{x}(k,\ 0),$$
$$\underset{\sim}{x}(k,\ k' + 1) = \underset{\sim}{x}(k,\ k') + \underset{\sim}{\Delta}(k,\ k'),$$
$$\underset{\sim}{x}(k + 1) = \underset{\sim}{x}(k,\ q);$$

k' is added to the g and f function arguments. This capability impli
an additional step, 5a, in the above sequence:

(5a) Increment k' and compare to q where q is the resolution ratio. If less than q, return to step 2, otherwise proceed to step 6.

Processing of a ghost (REFLEX) module, one that has control over
submodules, requires a modified procedure; steps 3, 4, and 5 are repla
by step 3a:

(3a) Call and process subsystems (submodules), which in turn upda
the values of the state variables in ghost. Then continue with step 5a.

The current FLEX algorithm assumes that a division of one time-s
into q subintervals within a terminal (FLEX) module is being done to
implement a solution to a set of differential equations, and accordin
only 1/q of the update (Δ) value is added to each variable. In modul
S_1 of version 3, this capacity is used differently; an event structur
is **assumed** and a full update on each variable is desired. Because
q = 10 (representing the 10 occasions in a season), each f function i
multiplied by 10 to nullify the automatic multiplication by 1/q (Whit
and Overton 1977, p. 21 and 32).

computational convenience internal to the FORTRAN code of a function (e.g., a g function). These are available to no other functions and will not appear in the list of explicit state variables.

VECTOR PROCESSING IN FLEX2

The current version of the DFTM stand-outbreak model makes use o some of the conceptual structure of the FLEX paradigm that is not explicitly a part of the current algorithm used by the model processo as detailed in the FLEX users manual. The following explanation will clarify a newly adopted notational convention, its conceptual meaning the paradigm, its place in the algorithm, and its implementation usin the current version of the processor.

In the FLEX paradigm, $\underset{\sim}{x}$, the vector of state variables, may cont elements that are themselves vectors--usually when a class II system being considered, a system in which each subsystem has the same struc and function, as in a population of individuals that have the same ru of behavior. Thus, $\underset{\sim}{x}_i$ may be an element of $\underset{\sim}{x}$. For example, $\underset{\sim}{x}_i$ might represent the biomasses of each of the individuals in a population, w an element of $\underset{\sim}{x}_i$ the biomass of a particular individual. The notatio convention is established that $\underset{\sim}{x}$ is the vector of state variables; $\underset{\sim}{x}_i$ a vector element of $\underset{\sim}{x}$; and x_{ij} is a scalar element of $\underset{\sim}{x}_i$.

Only the homogeneous case is allowed, so that each member subsys of the class II system has the same state variable structure. A g fu that operates on $\underset{\sim}{x}_i$ is a vector valued function. $\underset{\sim}{g}$ is the vector of intermediate functions with g_i an element of this vector. $\hat{g}_i$ is a sc value of g_i where the caret notation is used to signify an actual val of the function. When g_i operates on the vector $\underset{\sim}{x}$, it may produce a vector $\underset{\sim}{\hat{g}}_i$. The values generated by operation of $\underset{\sim}{g}$ on $\underset{\sim}{x}$ form a matrix corresponding to the ith element of $\underset{\sim}{g}$ and the jth member of the popul Then the notation $\hat{g}_{.j}$ denotes the column vector of values for all g f for the jth population member, and the notation $\underset{\sim}{\hat{g}}_{i.}$ represents the ro vector of values of the ith g function for all population members. A similar notation is extended to the function vectors $\underset{\sim}{z}$ and $\underset{\sim}{y}$; $\underset{\sim}{b}$ and r parameter vectors may also have vector elements.

Introduction of the ability to cycle through a single subsystem specified number of times, with each cycle processing in turn a membe of a population of identically structured subsystems, required modification in the FLEX algorithm. Instead of incrementing k' automatical after each pass through the subsystem, counter k" is incremented afte each pass and then checked against p. The population number, p, is s before a simulation run. If the subsystem has not been processed p times, then the g functions are called and the subsystem is processed again. The values $\underset{\sim}{\hat{g}}_{.j}$ are calculated, the updated values of $\underset{\sim}{x}_{.j}$ are and k" and j are incremented. After cycling p times, the vector elem of g and $\underset{\sim}{x}$ have been updated; k' is then incremented and the next pas through the g functions will fix $\underset{\sim}{\hat{g}}_{.1}$ before the first call to the sub for that time step.

ate variables, $\underset{\sim}{X}$, is updated by column vectors and the values $\underset{\sim}{G}$ are lculated by column vectors. It implies, however, that internal storag cations for the values $\hat{g}_{ij}$, x_{ij}, etc., are within the processor. Thes cations do not exist in the current processor version. Vector values st be stored on external files that are accessed, manipulated, and dated by the various functions and subroutines that use them.

The following procedure is used to implement this algorithm feature the current processor version. At k' = 0, the g functions are called usual. In a ghost module, each g_i, may operate in a different mode. g_i may calculate $\hat{g}_{i\cdot}$ at this time and store it on an external file. A y calculate only a scalar value and have it available in the standard y for use by other g_i's. Or a g_i may be used to process external file itialize the state variable and input variable matrices, and store em on external files for subsystem access. Each time the subsystem is ocessed, the functions within the subsystem reads ghost's $\hat{g}_{\cdot j}$ from the le. The g functions in the subsystem generate only that subsystem's lumn vector $\hat{g}_{\cdot j}$, and these values are stored in the processor and are cessed in the standard way. The subsystem's updated values of $\underset{\sim}{x}_{\cdot j}$ are ored on a different external file, not in the ghost module. On comple subsystem processing, the functions in the ghost module may then cess those files as necessary.

The above procedure introduces a new level of complexity in FLEX ograming. Much of this complexity could be avoided by introducing a y level in the hierarchy, but this entails difficulties as well as creasing processing time and cost. The approach used here is relative expensive and easily implemented.

CORRESPONDENCE OF THE THREE MODEL VERSIONS

The model for interaction of the tussock moth larvae and host liage was originally conceptualized and developed in terms of daily solution mechanisms. Table 1 defines the daily resolution occasion ructure of version 1.2. This model was restructured into the instar solution of table 2 for version 2.2. Only one change in the conceptua ructure is necessitated by this change in resolution. The model owth and feeding of the tussock moth is altered in the fourth instar accommodate the convolution of larval growth with population survival er an instar. This is accomplished by assuming that the growth rate constant throughout this instar, at the average of the two growth tes used during this instar in version 1.2. This changes the accumula rval biomass, but only slightly and only during the fourth instar.

The organization of the models by subsystem and function identifica shown in table 3. The subsystems are those of the branch model at th daily and instar resolution. The g functions, although representin same processes, do change form from version 1.2 to version 2.2. The tails of the functional forms are given in the FLEXFORMS that follow.

del of module S_1 of version 3.1 (see figure 3). The only changes cessary are:

(i) some "normal tree" parameters are being brought in as z input ther than being internal b parameters;

(ii) the time index is changed from k to k';

(iii) the overwintering activities of occasion 10 of table 2 take ace in the ghost module S_0 of version 3.1. The details of these anges are presented in the version 3.1 FLEXFORMS.

Table 1 --Douglas-fir tussock moth population-branch model, daily resolution form, Version 1.2. Occasion/time structure: note that occasion t is the interval before time k; k = t-1 during occasion t

Occasion	Description
Initiation	Bud burst and shoot elongation complete.
1	Egg hatch and establishment of first instars.
2	First day of feeding, growth, and mortality.
.	
.	
.	
10	Ninth day of feeding, growth, and mortality.
11	Last day larvae are in the first instar: feeding, growth, and mortality.
.	
.	
.	
21	Last day larvae are in the second instar: feeding, growth, and mortality.
.	
.	
.	
31	etc.
.	
.	
.	
41	etc.
.	
.	
.	
51	Last day larvae are in the fifth instar: feeding, growth, mortality, and male pupation.
.	
.	
.	
61	Last day of sixth instar: feeding, growth, mortality, and female pupation.
62	Pupal mortality and adult female emergence.
63	Eggs laid, aging of new foliage, and new foliage potential set. Redistribution of insects over the stand.[1]
64	Overwinter mortality of foliage. Overwinter mortality of eggs.[2]

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[1] This is not operative in a single-tree run, only in the stand-outbreak model.

[2] Overwinter mortality accounts for all the mortality factors to which the egg masses are subjected between the time they are laid in the fall and hatch in the spring. In the current version, it also implicitly accounts for the mortality between hatching and establishment of first instars.

Occasion/time structure

Occasion	Description
Initiation	Bud burst and shoot elongation complete.
1	Egg hatch, establishment on foliage.
2	First instars: feeding, growth, and mortality.
3	Second instars: feeding, growth, and mortality.
4	Third instars: feeding, growth, and mortality.
5	Fourth instars: feeding, growth, and mortality.
6	Fifth instars: feeding, growth, and mortality. Male pupation occurs after fifth-instar feeding.
7	Sixth instars (female): feeding, growth, mortality, and female pupation.
8	Pupal mortality and adult female emergence.
9	Eggs laid, aging of foliage, and new foliage potential set.
10	Redistribution of eggs.[1] Overwinter mortality of foliage and overwinter mortality of eggs.

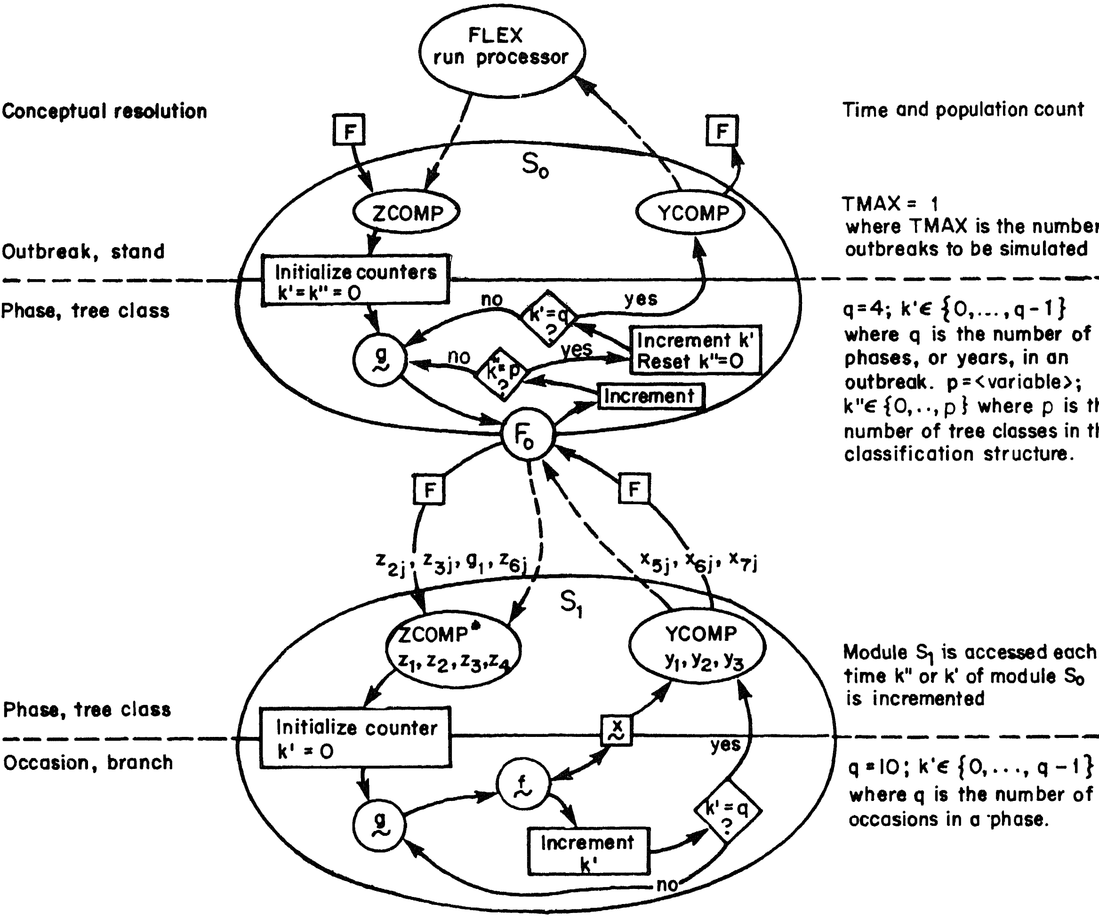
---

[1] In Version 3.1, the events of occasion 10 take place in module S_0.

Table 3 --G function assignment by subsystems for the three model versions

Subsystems (S_j): 1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

Subsystems	G Functions	Identity
	Versions 1.2 & 2.2 and Version 3.1 Lower Module	
S_1:	1, 4	New foliage destruction and production.
	2, 5	Old foliage destruction and (for V1 and V2) mortality.
	3	Aging of new foliage into old.
S_2:	6, 7, 8	Determination of daily larval mortality.
	9	Index of days spent feeding on old foliage.
	10	Fecundity or special occasion mortality.
	11	Total mortality (or egg production).
S_3:	12	Nominal larval growth rate.
	13	Achieved larval growth.
	14	Fecundity stress index.
	15, 16, 17, 18	Food demand and function for allocation of demand to new and old foliage.
	19	Index of day on which foliage was depleted by feeding.
	Version 3.1 Upper Module	
	1	Phase or year of the outbreak.
	2	Redistribution of insects over the stand.
	3	Old foliage mortality.
	4	Overwinter mortality of eggs.



*ZCOMP sets the values in S_1 of $b_1, \ldots, b_6, b_{34}, b_{35}, b_{36}$, and $r_1, \ldots, r_{12}$ according to the value of z_3, and $r_{13}, \ldots, r_{18}$ according to the value of z_4. Also, the values of x_{5j}, x_{6j}, and x_{7j} of S_0 become the initial conditions for x_1, x_2, and x_3 of S_1, respectively, and x_4 of S_1 is initialized to zero.

F external file

Figure 3.--Stand-outbreak model, Version 3.1: Module stacking and sequencing. Note: The ovals marked ZCOMP and YCOMP represent the FLEX input and output variable processor subroutines, respectively, for each module. This figure follows the convention of figures 5 and 6 in White and Overton (1977). The F's in boxes are external data files used in data storage and module coupling. For details, see page 46. Couplings between S_0 and S_1 are given in terms of variables of S_0.

FLEXFORMS: V1.2; V2.2; V3.1 MODULE S_0; V3.1, MODULE

FLEXFORM: V1.2
Page 1 of 12

TITLE: DFTM Population-Branch Model,
Version 1.2

DATE: March 8, 1974
March 15, 1977 (revised)

INVESTIGATORS: Overton, White, Hunt,
Colbert

TEMPORAL RESOLUTION: day, occasion; duration of run, one season.

SPATIAL RESOLUTION: the hypothetical model branch.

QUANTITIES MODELED: Biomass (dry weight) of foliage and larva,
numbers of insects.

Note: Conceptually this model can be treated as one occasion in an annual resolution model, with the annual quantities:

1. Annual variables
    - (i) actual foliage complement
        - a) new foliage biomass
        - b) old foliage biomass
    - (ii) viable egg density
2. "Phase-specific" parameters
    - (i) egg-mass size
    - (ii) disease, parasite/predator mortality rates
    - (iii) overwinter egg and larval establishment mortality ra
3. Parameters that originate as "branch-outbreak" variables
parameters
    - (i) nominal foliage complements
    - (ii) Phase I initial viable egg density
    - (iii) host specific mortality rates
    - (iv) (host species)

SUBSYSTEMS:

1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

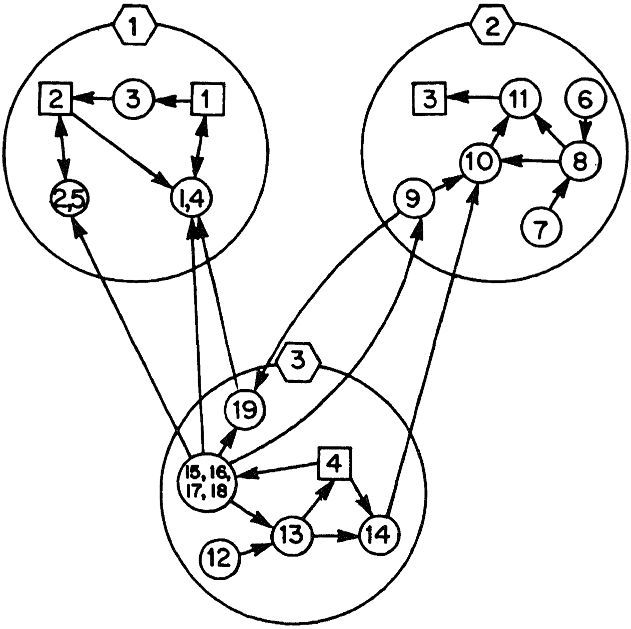
Symbol Key:

⬡ Subsystem designatio

○ System, subsystem, p
function. Numbers i
circles are g functi

☐ State variables.

DIAGRAM:



VARIABLES AND FUNCTIONS

1. X List

Variable	Description	Units
x_1	New foliage biomass ($0 \leq k \leq 62$) and new foliage potential for the next year ($k = 63, 64$).	g
x_2	Old foliage biomass.	g
x_3	Viable eggs ($k = 0$). Established first instars ($k = 1$). Feeding larvae, male and female ($1 < k \leq 50$). Feeding female larvae ($51 \leq k \leq 60$). Female pupae ($k = 61$). Adult females emerged ($k = 62$). Viable eggs produced ($k = 63$). Viable eggs after overwinter mortality ($k = 64$).	numbe
x_4	Individual larval biomass.	mg
x_5	Individual larval biomass at $k = 36$.	mg

---

2. Z Functions

No inputs other than initial conditions are needed in this single-year version of the model. Phase-specific "inputs" are incorporated as parameters.

---

3. G Functions

Functional Form and Description	Units
$$g_1 = \begin{cases} \dfrac{b_{37}}{100} \cdot b_{38} \left[\dfrac{x_1 + x_2 + b_{38}}{2b_{38}} - g_{19} b_{32} \right] & \text{for } k = 62 \\ 0 & \text{otherwise.} \end{cases}$$	g

This function accounts for the capacity to produce new foliage (g-dryweight) after the completion of feeding by the DFTM ($k = 62$) and before the overwinter needle drop. If feeding results in total defoliation, then new foliage is reduced in proportion to the number of days of total defoliation (g_{19}).

---

nctional Form and Description Units

$$= \begin{cases} \max\left[0,\ x_2 - b_{38}\left(1 - \frac{b_{37}}{100}\right)\right] & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases} \qquad g$$

edle drop or litter production (g-dryweight) from the branch. This ocess is required to keep the branch in equilibrium under normal nditions.

$$= \begin{cases} x_1 \text{ for } k = 62, & \text{Aging of new foliage to old foliage.} \\ 0 \text{ otherwise.} & \end{cases} \qquad g$$

$$= \begin{cases} \min(g_{16}, x_1) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \qquad g$$

struction of new foliage (g-dryweight) for each day of feeding (1 ≤ k

---

$$= \begin{cases} \min(g_{18} - g_4, x_2) & \text{for } 1 \leq k \leq 60 \text{ and } g_4 < g_{16}, \\ 0 & \text{otherwise.} \end{cases} \qquad g$$

struction of old foliage (g-dryweight) for each day of feeding (1 ≤ k which demand for food can not be fully satisfied by feeding new foliage.

$$= \begin{cases} (1 - r_{s_1})(1 - r_{s_1+6})(1 - b_{s_1}) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \qquad d^{-1}$$

e survivorship per day (d^{-1}) associated with disease mortality (r_{s_1}), edator and parasite mortality (r_{s_1+6}), and background mortality $_{s_1}$). Each is instar specific (see special function s_1).

Functional Form and Description U

$$g_7 = \begin{cases} 1 - r_{s_1} + 12 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$

The daily survivorship associated with stress from feeding on old foliage; instar specific.

$$g_8 = \begin{cases} g_6 g_7^{\,1-g_{15}} - 1 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$

Negative total daily mortality rate. [Assume $0^0 \equiv 1$.]

$$g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } k - 63, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases}$$

(implicitly, $x_1^*(k+1) = x_1^*(k) + g_{17}(k)$)

Total number of days (d) spent feeding on old foliage during which demands are fully satisfied.

$$g_{10} = \begin{cases} -b_{39} & \text{for } k = 0, \\ -b_{34}(1 + g_8) & \text{for } k = 50, \\ -b_{26} & \text{for } k = 61, \\ b_{27}\, g_{14}(1 - b_{33} g_9) - 1 & \text{for } k = 62, \\ -b_{35} & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases}$$

numbe

This function accounts for changes in number of larvae from establishment mortality (k = 0), male pupation (k = 50), female pupal mortality (k = 61), viable eggs produced by the remaining females (k = 62), and overwinter mortality (k = 63). Fecundity is reduced in proportion to the number of days spent feeding on old foliage (g_9) and the final weight of the female larva (g_{14}).

Functional Form and Description — Units

$$g_{11} = (g_8 + g_{10})x_3$$

Larval mortality, male pupation, pupal mortality, egg production.

Units: number

$$g_{12} = \begin{cases} b_{22} & \text{for } 1 \leq k \leq 35, \\ b_{23} & \text{for } 36 \leq k \leq 60, \\ 0 & \text{for } x_3 \leq 0 \text{ or} \\ & x_1 + x_2 \leq 0 \text{ or} \\ & k = 0 \text{ or } k \geq 61. \end{cases}$$

The nominal instantaneous larval growth rate. Larvae grow at the nominal rate as long as food is available.

Units: d^{-1}

$$g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{\phi g_{12}} - 1) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{for } k \geq 61. \end{cases}$$

Units: mg

Here

$$\phi = \begin{cases} \dfrac{g_4 + g_5}{g_{15}g_{16} + g_{17}g_{18}} & \text{for } (g_{15} + g_{17}) \neq 0, \\[2ex] \dfrac{g_4 + g_5}{g_{18}} & \text{for } (g_{15} + g_{17}) = 0. \end{cases}$$

Achieved larval growth increment. The proportion ϕ is the ratio of actual foliage destruction to total foliage demand; if less than one, then the larvae did not feed for the full day and hence the growth is reduced according to the proportion ϕ.

$$g_{14} = \max \left[\frac{2x4}{b_{24}} - 1, 0\right]$$

Fecundity stress index, which is measured relative to the nominal final biomass (b_{24}).

Units: none

$$g_{15} = \begin{cases} 1 \text{ if } g_{16} < x_1 \\ \quad \text{and } 1 \leq k \leq 60, \\ 0 \text{ otherwise.} \end{cases}$$

The indicator of a day spent feeding exclusively on new foliage.

Units: d

Functional Form and Description

$$g_{16} = \begin{cases} b_{s_1} + 6 \left[\frac{10^{-3}}{b_{21}} \left(b_{19} + \frac{b_{20}}{g_{12}}\right)\left(e^{g_{12}} - 1\right) \right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$

New foliage demand for the day's feeding and growth.

$$g_{17} = \begin{cases} 1 \text{ if } g_{15} = 0, \\ \quad 1 \leq k \leq 60, \text{ and } (x_1 + x_2) > g_{18}, \\ 0 \text{ otherwise.} \end{cases}$$

The indicator of a day spent feeding on old foliage with demand completely satisfied.

$$g_{18} = \begin{cases} b_{s_1} + 12 \left[\frac{10^{-3}}{b_{21}} \left(b_{19} + \frac{b_{20}}{g_{12}}\right)\left(e^{g_{12}} - 1\right) \right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$$

Old foliage demand for the day's feeding and growth.

$$g_{19} = \begin{cases} 60 - [x_2^* + g_9] & \text{for } k = 62, \\ 0 & \text{otherwise.} \end{cases}$$

(implicitly, $x_2^* (k+1) = x_2^* (k) + g_{15}(k)$)

Total number of days during the larval period for which food demands were not fully satisfied.

nctional Form and Description

$$)^{4/} = \begin{cases} 0 & \text{for } k = 0,\ x_3 \le 0,\ x_1 + x_2 \le 0, \text{ or } k \ge 61, \ [1] \\ b_{22} & \text{for } k = 1 \text{ or } [x_4 \ge (1 - b_{31})g_{21} \text{ and } 2 \le k \le 35], \ [2] \\ \dfrac{\ln(x_4/b_{25})}{k-1} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 2 \le k \le 35, \ [3] \\ b_{23} & \text{for } k = 36 \text{ or } [x_4 \ge (1 - b_{31})g_{21} \text{ and } 37 \le k \le 60], \ [4] \\ \dfrac{\ln(x_4/x_5)}{k-36} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 37 \le k \le 60. \ [5] \end{cases}$$

e modified growth rate of an individual larva. [3] and
] are growth rates for trajectories below the normal; [2]
d [4] for normal trajectories.

$$1^{4/} = \begin{cases} b_{25}e^{b_{22}k} & \text{for } 0 \le k \le 35, \\ b_{25}e^{35b_{22} + (k - 35)b_{23}} & \text{for } 36 \le k \le 60, \\ b_{25}e^{35b_{22} + 25b_{23}} & \text{otherwise.} \end{cases}$$

minal larval growth trajectory.

$$22^{4/} = \begin{cases} x_4 & \text{if } k = 36, \\ 0 & \text{otherwise.} \end{cases}$$

Larval biomass after 35 days of feeding, benchmark for determining reduced growth rate.

$$23^{4/} = \max \left\{ 2 \left[\frac{x_4 + g_{13}}{g_{21}} \right] - 1,\ 0 \right\}$$

Fecundity stress index.

$^{4/}$ Note: These four g-functions are not operational, but are given here
exhibit how variable growth rates for the larvae might be implemented if
itional food becomes available after foliage is depleted. The functions g
g_{23} would replace the present g_{12} and g_{14}, respectively.

4. F Functions

Functional Form and Description		Units
$f_{1,1} = g_1 - g_4$	See state variables X list, for descriptions.	g
$f_{1,2} = g_3$		g
$f_{2,2} = -g_5 - g_2$		g
$f_{3,3} = g_{11}$		number
$f_{4,4} = g_{13}$		mg
$f_{5,5} = g_{22}$		mg

5. Y Functions

Functional Form and Description		Units
$y_i = x_i$,	$i = 1, 2, 3, 4$	See X list for descriptions and units.

6. Special Functions

Functional Form and Description		Units
s_1[5/] $= \left[\frac{k-1}{10}\right] + 1$	The current instar of the population.	none

PARAMETERS

7. B Parameters

$b_1, \ldots, b_{22}$ identical to $b_1, \ldots, b_{22}$ of Version 2.2. See page 7, 8 of Version 2.2 FLEXFORM.

[5/] Note: For this function, [x] is the largest integer that does not exceed the magnitude of x.

List	Value	Description	Units
b_{23}	0.0625	Instantaneous growth rate for $36 \le k \le 60$.	d^{-1}
b_{24}	52.063	Nominal biomass of female larvae at the end of the sixth instar, $k = 61$.	mg
b_{25}	0.197	Initial nominal biomass of larvae after establishment.	mg
b_{26}	I, .50; II, 0.62; III, .75; IV, .90	Phase-specific pupal mortality rate.	occasi
b_{27}	I, 200; II, 200; III, 150; IV, 150.	Phase-specific nominal egg-mass size.	numbe
b_{28}	(not used)		
b_{29}	(not used)		
b_{30}	(not used)		
b_{31}	1.0×10^{-8}	Error tolerance in larval growth trajectory.	none
b_{32}	0.02	Coefficient of reduction in bud capacity from total branch defoliation.	d^{-1}
b_{33}	0.01	Coefficient of reduction in fecundity from feeding on old foliage.	d^{-1}
b_{34}	0.50	Proportion of larvae that are male at the end of the fifth instar.	none
b_{35}	I, .50; II, .60; III, .85; IV, .90.	Overwinter mortality.	occasi
b_{36}	1, 2, 3 or 4	Phase index.	none
b_{37}[6/]		Nominal percent of new foliage.	none
b_{38}[6/]		Nominal total foliage biomass per model branch.	g
b_{39}	0.0	Phase-specific larval establishment mortality.	occasi

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[6/] The values of b_{37} and b_{38} are chosen according to the properties host tree for a particular simulation.

8. R Parameters

List	Value I	Value II	Value III	Value IV	Instar	Description	Unit
r_1	0.0	0.0	0.002	0.025	1st	Instar and phase-specific daily disease mortality rate.	d^{-}
r_2	0.0	0.0	0.003	0.028	2nd		
r_3	0.0	0.0	0.006	0.031	3rd		
r_4	0.0	0.0	0.013	0.034	4th		
r_5	0.0	0.001	0.035	0.035	5th		
r_6	0.0	0.001	0.028	0.035	6th		
r_7	0.0	0.0	0.001	0.005	1st	Instar- and phase-specific daily predator/parasite mortality rate.	d^{-1}
r_8	0.0	0.0	0.002	0.006	2nd		
r_9	0.0	0.0	0.003	0.007	3rd		
r_{10}	0.0	0.0	0.010	0.021	4th		
r_{11}	0.0	0.001	0.016	0.033	5th		
r_{12}	0.0	0.001	0.042	0.056	6th		

List	Douglas-fir	Grand fir	Instar	Description	Unit
r_{13}	1.0	1.0	1st	Instar- and host-specific daily food stress mortality rate.	d^{-1}
r_{14}	0.75	0.8	2nd		
r_{15}	0.10	0.5	3rd		
r_{16}	0.0	0.1	4th		
r_{17}	0.0	0.0	5th		
r_{18}	0.0	0.0	6th		

. Initial Conditions[7]

x_1	50.4
x_2	93.6
x_3	3.5
x_4	0.0

ENERAL RUN INFORMATION

TSTART = 0

TMAX = 64

q = 1

LP, DUMP[8]: All y's, all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for documentati purposes and was run only to verify model output against V3.1.

Source code file: DAILY

FLEX3 overlay[9]: *DAILY

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[7] The full range of admissible initial conditions is available from th thors upon request.

[8] LP stands for "line printer". DUMP stands for "dump file", a file us r compact storage of the details of a simulation for later review or recon ruction.

[9] "Overlay" as used here is the machine-executable code, and is called bsolute element" on some other computers.

TITLE: DFTM Population-Branch Model
Version 2.2

INVESTIGATORS: Overton, Colbert, Whit

DATE: December 1, 1975

March 15, 1977 (revised)

TEMPORAL RESOLUTION: instar, occasion; duration of run is one seas

SPATIAL RESOLUTION: the hypothetical model branch

QUANTITIES MODELED: biomass (dry weight) of foliage and larvae;
number of insects

SUBSYSTEMS:
1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

DIAGRAM:

(See the diagram on page 2 of Version 1.2 FLEXFORM.)

VARIABLES AND FUNCTIONS

1. X List

List	Description	Units
x_1	New foliage biomass	g
x_2	Old foliage biomass	g
x_3	Viable eggs, k = 0.	number
	Established first instars (k = 1).	
	Feeding larvae, male and female (k = 2, 3, 4, 5).	
	Feeding female larvae (k = 6).	
	Female pupae (k = 7).	
	Adult female moths (k = 8).	
	Viable eggs produced (k = 9).	
	Viable eggs after overwinter mortality (k = 10).	
x_4	Individual larval biomass	mg

2. Z Functions

No inputs, other than initial conditions, are in this sin year version of the model. Phase-specific "inputs" are incorp as parameters.

3. G Functions

Functional Form and Description[10]

$$g_1 = \begin{cases} \frac{b_{31}b_{32}}{100}\left[\frac{x_1 + x_2 + b_{32}}{2b_{32}} - g_{19}b_{27}\right] & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$$

New foliage capacity.

$$g_2 = \begin{cases} \max\left[0,\ x_2 - b_{32}(1 - \frac{b_{31}}{100})\right] & \text{for } k = 9, \text{ Needle drop.} \\ 0 & \text{otherwise.} \end{cases}$$

$$g_3 = \begin{cases} x_1 & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$$

Aging of new foliage.

$$g_4 = \begin{cases} \min(g_{16},\ x_1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$$

Destruction of new foliage.

$$g_5 = \begin{cases} \min(g_{18},\ x_2) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$$

Destruction of ol foliage.

---

[10] For more complete descriptions see Version 1.2 FLEXFORM.

Functional Form and Description Units

$$g_6 = \begin{cases} (1 - r_k)(1 - r_{k+6})(1 - b_k) & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$

d^{-1}

Daily survivorship after disease, predator/parasite, and background mortality.

$$g_7 = \begin{cases} 1 - r_{k+12} & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$

d^{-1}

Daily survivorship after food stress.

$$g_8 = \begin{cases} g_6^{10} \; g_7^{10-g_{15}} - 1 & \text{for } 1 \le k \le 6, \\ 0 & \text{otherwise.} \end{cases}$$

none

Negative total mortality rate for an instar. [Assume $0^0 \equiv 1$.]

$$g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases}$$

d

(Implicitly, $x_1^*(k + 1) = x_1^*(k) + g_{17}(k)$)

Total number of days spent feeding on old foliage during which demand is fully satisfied.

Special Occasion Processes:

$$g_{10} = \begin{cases} -b_{36} & \text{for } k = 0\text{, Establishment mortality.} \\ -b_{30}(1 + g_8) & \text{for } k = 5\text{, Male pupation.} \\ -b_{34} & \text{for } k = 7\text{, Female pupal mortality.} \\ b_{35}g_{14}(1 - b_{28}g_9) - 1 & \\ & \text{for } k = 8\text{, Viable eggs produced.} \\ -b_{37} & \text{for } k = 9\text{, Overwinter mortality.} \\ 0 & \text{otherwise.} \end{cases}$$

none

Functional Form and Description Units

$$g_{11} = (g_8 + g_{10})x_3$$

Larval mortality, male pupation, pupal mortality, egg production, and overwinter mortality.

numbe

$$g_{12} = \begin{cases} 0 & \text{for } x_3 \leq 0, \\ & (x_1 + x_2) \leq 0, \text{ or } k > 6, \\ b_{22} & \text{for } 1 \leq k < 4, \\ b_{23} & \text{for } k = 4, \\ b_{24} & \text{for } 4 < k \leq 6. \end{cases}$$

Instantaneous daily growth rate.

d^{-1}

$$g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{[10\phi g_{12}]} - 1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k > 6, \end{cases}$$

mg

where

$$\phi = \left[\frac{g_4 + g_5}{g_4 + g_{18}}\right]$$

Achieved larval growth increment for an instar. The proportion ϕ is the ratio of actual needle destruction to total needle demand; if less than one, the larvae did not feed all 10 days, and the number of days spent growing is reduced according to the proportion ϕ.

$$g_{14} = \max\left[\frac{2x_4}{b_{26}} - 1,\ 0\right]$$

Fecundity stress index.

none

$$g_{15} = \begin{cases} \alpha & \text{where } \alpha \in \{0, 1, \ldots, 10\} \text{ is} \\ & \text{the largest integer such that} \\ & \text{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, \alpha) < x_1, \\ 0 & \text{for } k = 0 \text{ or } k > 6 \text{ or if no } \alpha \text{ exists that} \\ & \text{satisfies the above inequity.} \end{cases}$$

d

Time spent feeding exclusively on new foliage.

Functional Form and Description	Unit
$g_{16} = \begin{cases} \mathrm{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, \min[g_{15} + 1, 10]) & \text{for } x_1 > 0 \text{ and } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$ Total new foliage demand.	g
$g_{17} = \begin{cases} \eta & \text{where } \eta \in \{0, 1, \ldots, 10 - g_{15}\} \\ & \text{is the smallest integer such that} \\ & [\mathrm{UV2}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}, \eta + 1) - \\ & (x_1 - \mathrm{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}))] > x_2 \text{ and} \\ 10 - g_{15} & \text{otherwise for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases}$ The number of days spent feeding on old foliage for which demand is fully satisfied.	d
$g_{18} = \begin{cases} \max[\mathrm{UV2}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15}, 10 - g_{15}) - \\ (x_1 - \mathrm{UV1}(k, \underset{\sim}{x}, \underset{\sim}{b}, g_{15})), & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases}$ Total old foliage demand for remainder of the instar.	g
$g_{19} = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_2^* & \text{for } k = 7 \text{ or } 8, \\ x_2^* + 10 - [g_{15} + g_{17}] & \text{otherwise.} \end{cases}$ (Implicitly, $x_2^*(k + 1) = x_2^*(k) + 10 - [g_{15}(k) + g_{17}(k)]$). Total number of days during which demand for food is not fully satisfied.	g

4. F Functions

Functional Form and Description		Un
$$\left.\begin{aligned} f_{1,1} &= g_1 - g_4 \\ f_{1,2} &= g_3 \\ f_{2,2} &= -g_5 - g_2 \\ f_{3,3} &= g_{11} \\ f_{4,4} &= g_{13} \end{aligned}\right\}$$	See state variables, X list, for descriptions.	num m

5. Y Functions

$y_i = x_i$, $i = 1, 2, 3, 4$ See X list for description and units.

6. Special Functions

Functional Form and Description	Un

$$UV1(k,\ \underset{\sim}{x},\ \underset{\sim}{b},\ \alpha) = U(\underset{\sim}{x},\ \underset{\sim}{b},\ k)\ .\ V_1(\underset{\sim}{b},\ \alpha,\ k),$$

where

$$U(\underset{\sim}{x},\ \underset{\sim}{b},\ k) = \frac{10^{-3}}{b_{21}}\left[b_{19} + \frac{b_{20}}{g_{12}}\right](e^{g_{12}} - 1)x_3x_4,$$

$$V_1(\underset{\sim}{b},\ \alpha,\ k) = b_{6+k}\ \frac{1 - \left[g_6 e^{g_{12}}\right]^{\alpha}}{1 - g_6 e^{g_{12}}},$$

and

$$UV1 = 0 \text{ for } k \notin \{1, \ldots, 6\}.$$

Total new foliage demand for an instar. U is the food demand for metabolism and growth, V_1 is the product of the destruction/consumption ratio and the convolution of daily larval growth and daily larval survivorship during feeding on new foliage. See g_{14} and g_{15}.

Functional Form and Description	Units
$UV2(k, \underset{\sim}{x}, \underset{\sim}{b}, \alpha, \eta) = U(\underset{\sim}{x}, \underset{\sim}{b}, k) \cdot V_2(\underset{\sim}{b}, \alpha, \eta, k).$	g

where U is given in UV1 above

and

$$V_2(\underset{\sim}{b}, \alpha, \eta, k) = b_{12+k} g_6^{\alpha} e^{\alpha g_{12}} \left[\frac{1 - \left[g_6 g_7 e^{g_{12}} \right]^{\eta}}{1 - \left[g_6 g_7 e^{g_{12}} \right]} \right]$$

$UV2 = 0$ for $k \notin \{1, \ldots, 6\}$

Total old foliage demand for an instar. U is the food demand for metabolism and growth, V_2 is the product of the destruction/consumption ratio with the convolution of the daily larval growth and daily larval survivorship during feeding on old foliage.

PARAMETERS

7. B Parameters

List	Value	Instar	Description	Unit
b_1	0.02	1st	Instar-specific background daily mortality rate.	d^{-1}
b_2	0.02	2nd		
b_3	0.02	3rd		
b_4	0.02	4th		
b_5	0.02	5th		
b_6	0.02	6th		
b_7	5.4	1st	Instar-specific destruction/consumption ratio for feeding on new foliage.	non
b_8	6.25	2nd		
b_9	6.25	3rd		
b_{10}	2.71	4th		
b_{11}	2.27	5th		
b_{12}	2.0	6th		
b_{13}	5.4	1st	Instar-specific destruction/consumption ratio for feeding on old foliage.	no
b_{14}	6.25	2nd		
b_{15}	6.25	3rd		
b_{16}	3.69	4th		
b_{17}	3.29	5th		
b_{18}	3.0	6th		

List	Value	Description	Uni
b_{19}	1.19	Assimilated food, growth coefficient.	nor
b_{20}	0.081	Assimilated food, respiration coefficient.	d^{-1}
b_{21}	0.10	Assimilation efficiency.	nor
b_{22}	0.1147	Instantaneous growth rate for first three instars.	d^{-1}
b_{23}	0.0886	Instantaneous growth rate for fourth instar.	d^{-1}
b_{24}	0.0625	Instantaneous growth rate for fifth and sixth instars.	d^{-1}
b_{25}	0.197	Initial biomass of larvae at hatch.	mg
b_{26}	52.063	Nominal biomass of female larvae at the end of the sixth instar.	mg
b_{27}	0.02	Coefficient of reduction in bud capacity from total branch defoliation.	d^{-1}
b_{28}	0.01	Coefficient of reduction in fecundity from feeding on old foliage.	d^{-1}
b_{29}	1,2,3,4	Phase index.	nor
b_{30}	0.50	Proportion of larvae that are male at the end of the fifth instar.	nor
b_{31} [11/]		Nominal percent new foliage.	nor
b_{32} [11/]		Nominal total foliage biomass.	g
b_{33}	(not used)		
b_{34}	I:0.50; II:0.62; III:0.75; IV:0.80	Phase-specific pupal mortality rate.	occa
b_{35}	I,II:200; III,IV:150.	Phase-specific maximum egg-mass size.	nur
b_{36}	I,II,III, IV:0.0	Phase-specific establishment mortality rate.	occa
b_{37}	I:0.50; II:0.60; III:0.85; IV:0.90	Phase-specific overwinter mortality rate.	occa

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[11/] Note: b_{31} and b_{32} have values that depend on the host tree being simulated and are chosen, accordingly, prior to a specific simulation.

3. R Parameters

List	Value					Description	Units
	- Phase -				Instar		
	I	II	III	IV			
r_1	0.0	0.0	0.002	0.025	1st	Instar- and phase-specific daily disease mortality rate	d^{-1}
r_2	0.0	0.0	0.003	0.028	2nd		
r_3	0.0	0.0	0.006	0.031	3rd		
r_4	0.0	0.0	0.013	0.034	4th		
r_5	0.0	0.001	0.035	0.035	5th		
r_6	0.0	0.001	0.028	0.035	6th		
r_7	0.0	0.0	0.001	0.005	1st	Instar- and phase-specific daily predator/parasite mortality rate	d^{-1}
r_8	0.0	0.0	0.002	0.006	2nd		
r_9	0.0	0.0	0.003	0.007	3rd		
r_{10}	0.0	0.0	0.010	0.021	4th		
r_{11}	0.0	0.001	0.016	0.033	5th		
r_{12}	0.0	0.001	0.042	0.056	6th		

List	Douglas-fir	grand fir	Instar	Description	Units
r_{13}	1.0	1.0	1st	Instar- and host-specific daily food-stress mortality rate.	d^{-1}
r_{14}	0.75	0.8	2nd		
r_{15}	0.10	0.5	3rd		
r_{16}	0.0	0.1	4th		
r_{17}	0.0	0.0	5th		
r_{18}	0.0	0.0	6th		

9. Initial Conditions[12]

x_1	50.4
x_2	93.6
x_3	75.0
x_4	0.0

GENERAL RUN INFORMATION

TSTART = 0

TMAX = 10

q = 1

LP, DUMP: All y's; all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for the purpose of documentation and was run only to verify this model form against V3.1. See appendix B for v
fication output.

Source code file: INSTAR

FLEX3 overlay: *INSTAR

---

[12] These initial conditions, along with the phase II b and r param
for grand fir, were used to develop the appendix B verification output.

FLEXFORM: V3.1
MODULE: S_0
Page 1 of 7

TITLE: DFTM Stand-Outbreak Model Versio
Outbreak/Stand Module.

INVESTIGATORS: Overton, Colbert, White

DATE: September 17, 1976
March 15, 1977 (revised)

TEMPORAL RESOLUTION: Outbreak/phase.

SPATIAL RESOLUTION: Stand (by tree class).

QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae, numbe of insects per model branch, for each tree class.

DIAGRAM: See figure 3.

VARIABLES AND FUNCTIONS

1. X List

List	Phase	Description	Units
x_1	I	Weighted mean number of eggs per model branch over the tree classes of the stand.	number
x_2	II		
x_3	III		
x_4	IV		

The vector variables below contain an element for each tree class

List	Description	Units
$\underset{\sim}{x}_5$	Actual new foliage potential (on entry to S_1). Actual new foliage biomass (on exit from S_1).	g
$\underset{\sim}{x}_6$	Actual total foliage biomass (on entry to S_1). Actual old foliage biomass (on exit from S_1).	g
$\underset{\sim}{x}_7$	Number of viable eggs.	number

Z Functions[13]

st		Uni
1	The number of tree classes in the stand for the current model run. This number is entered by the user **during** a model run. This value is stored in b_{57} for use in computing the final weighted mean number of eggs. This is also the value of p in the input command file and must be set **before** a model run.	num

The vector variables below contain an element for each tree class:

2	Nominal percent new foliage.	no
3	Nominal total foliage biomass.	g
4	Number of trees.	num
5	Weighting factor.	no
6	Host species (1 = Douglas-fir, 2 = grand fir).	no

G Functions

nctional Form and Description		Uni
$= k' + 1$	Phase index.	num

$$_j^{14/} = \begin{cases} x_{7j} + b_{62}(x_{k'} - x_{7j}) & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases} \qquad \text{no}$$

distribution of viable eggs over the stand. (Implemented by call to special function REDIST.)

---

[13] Note: the z values are entered by the user in specifying a stand-tbreak model run.

[14] Functions g_2, g_3, and g_4 process all tree classes on the first pass rough the g functions each phase.

unctional Form and Description	Units
$_{3j}{}^{\underline{14/}} = \begin{cases} \min[x_{6j}, z_{3j}(1 - z_{2j}/100)] & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$ ld foliage survivorship.	g
$_{4j}{}^{\underline{14/}} = \begin{cases} (1 - b_{56+g_1})g_{2j} & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$ verwinter survival of eggs.	numb

. Y Functions

YCOMP calls REDIST for computation of the mean fall egg density ver the stand after phase IV. No y functions, per se, are included in his module. Instead, YCOMP accesses certain special functions to produ pecially formatted output tables. These are documented elsewhere see: Logical Unit Manipulation by User-Specified Functions).

Special Functions

ubroutine REDIST(k', n, $\underset{\sim}{b}$, $\underset{\sim}{x}$)

This subroutine first computes the mean egg density over he stand as follows:

$$x_{k'} = \frac{1}{T}\sum_{j=1}^{N} z_{4j}z_{5j}x_{7j}(k'),$$

here

$$T = \sum_{j=1}^{N} z_{4j}z_{5j}$$

nd N is the number of tree classes; z_{4j} is the number of trees in the h tree class; z_{5j} is the weight associated with a tree of the jth tree ass; x_{7j} is the number of viable eggs laid for the jth tree class; and $_{k'}$ is the fall mean egg density over the stand in phase k'.

The subroutine then redistributes the eggs over the stand according $\underset{\sim}{g}_2$.

PARAMETERS

6. B Parameters

	Value	Instar	Phase	Description
b_1	0.0	1st	I	Instar-specific disease mortality rate. (r_1, ..., r_6 in Version 2.2)
b_2	0.0	2nd		
b_3	0.0	3rd		
b_4	0.0	4th		
b_5	0.0	5th		
b_6	0.0	6th		
b_7	0.0	1st	II	
b_8	0.0	2nd		
b_9	0.0	3rd		
b_{10}	0.0	4th		
b_{11}	0.001	5th		
b_{12}	0.001	6th		
b_{13}	0.002	1st	III	
b_{14}	0.003	2nd		
b_{15}	0.006	3rd		
b_{16}	0.013	4th		
b_{17}	0.035	5th		
b_{18}	0.028	6th		
b_{19}	0.025	1st	IV	
b_{20}	0.028	2nd		
b_{21}	0.031	3rd		
b_{22}	0.034	4th		
b_{23}	0.035	5th		
b_{24}	0.035	6th		
b_{25}	0.0	1st	I	Instar-specific predator/parasite mortality rates. (r_7, ..., r_{12} in Version 2.2)
b_{26}	0.0	2nd		
b_{27}	0.0	3rd		
b_{28}	0.0	4th		
b_{29}	0.0	5th		
b_{30}	0.0	6th		
b_{31}	0.0	1st	II	
b_{32}	0.0	2nd		
b_{33}	0.0	3rd		
b_{34}	0.0	4th		
b_{35}	0.001	5th		
b_{36}	0.001	6th		

(continued)

Value	Instar	Phase	Description	Units
0.001	1st	III		
0.002	2nd			
0.003	3rd			
0.010	4th			
0.016	5th			
0.042	6th			
0.005	1st	IV		
0.006	2nd			
0.007	3rd			
0.021	4th			
0.033	5th			
0.056	6th			
0.50		I	Pupal mortality rate. (b_{34} in Version 2.2)	occasion^{-1}
0.62		II		
0.75		III		
0.80		IV		
200		I	Maximum egg-mass size eggs/mass (b_{35} in Version 2.2)	number
200		II		
150		III		
150		IV		
--			Number of tree classes (see z functions)	number
		Phase		
0.50		I	Overwinter mortality rate. (b_{37} in Version 2.2)	occasion^{-1}
0.60		II		
0.85		III		
0.90		IV		
0.0			Redistribution dispersal factor	none
0.0		I	Establishment mortality rate. (b_{36} in Version 2.2)	occasion^{-1}
0.0		II		
0.0		III		
0.0		IV		

7. R Parameters

	Value	Instar	Description	Un
r_1	1.0	1st	Instar-specific daily food stress[15] mortality rates for Douglas-fir host species. (r_{13}, ..., r_{18} in Version 2.2)	n
r_2	0.75	2nd		
r_3	0.10	3rd		
r_4	0.0	4th		
r_5	0.0	5th		
r_6	0.0	6th		
r_7	1.0	1st	Instar-specific daily food stress[15] mortality rates for the grand fir host species. (r_{13}, ..., r_{18} in Version 2.2)	n
r_8	0.8	2nd		
r_9	0.5	3rd		
r_{10}	0.1	4th		
r_{11}	0.0	5th		
r_{12}	0.0	6th		
r_{13}	0.02	1st	Instar-specific daily background mortality rate. (b_1, ..., b_6 in Version 2.2)	n
r_{14}	0.02	2nd		
r_{15}	0.02	3rd		
r_{16}	0.02	4th		
r_{17}	0.02	5th		
r_{18}	0.02	6th		

8. Initial Conditions

See appendix C for an example of the specification of initial conditions.

---

[15] Stress from feeding on old foliage during early instars.

GENERAL RUN INFORMATION

Module Sequence Number = 0

TMAX = 1   q = 4

Module type: ghost

Variables to be monitored: none.

Variables to be dump filed: none.

FILE NAMES

FLEX2 function overlay name: *V31SO

Source file name: V31SO

COMMENTS

Model behavior will be documented in a separate paper. A record
the model runs made in studying behavior will be included therein.
Appendix A contains the source code for Version 3.1 and the command f
for initializing a simulation. Appendix C contains the inputs and ou
from a verification simulation.

FLEXFORM: V3.1 TITLE: DFTM Stand-Outbreak Model,
MODULE: S_1 Version 3.1, Tree/Branch Module
Page 1 of 5 INVESTIGATORS: Overton, Colbert, White
DATE: September 17, 1976
March 15, 1977 (revised)

TEMPORAL RESOLUTION: Phase/instar, occasion.

SPATIAL RESOLUTION: Tree class/hypothetical model branch.

QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae,
of insects.

SUBSYSTEMS:
1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

DIAGRAM:

(See the diagram on page 2 of Version 1.2 FLEXFORM.)

VARIABLES AND FUNCTIONS

1. X List

List	Description	Units
x_1	New foliage biomass ($k' = 0, \ldots, 8$). New foliage potential for next year ($k' = 9, 10$).	g
x_2	Old foliage biomass.	g
x_3	Viable eggs ($k' = 0$). Larvae ($k' = 1, \ldots, 5$). Female larvae ($k' = 6$). Female pupae ($k' = 7$). Adult female moths ($k' = 8$). Viable eggs produced ($k' = 9, 10$).	number
x_4	Individual larval biomass.	mg

2. Input Variables

Z Functions

Functional Form	Description	Units
$z_1 = z_{2j}$ in S_0	Nominal percent new foliage.	none
$z_2 = z_{3j}$ in S_0	Nominal total foliage biomass.	g
$z_3 = g_1$ in S_0	Phase index.	none
$z_4 = z_{6j}$ in S_0	Host species index.	none

Parameter Assignments

B Parameters	Value, Description, and
$[b_1, \ldots, b_6] = [r_{13}, \ldots, r_{18}]$ in S_0, respectively, for $z_3 = 1, 2, 3, 4$.	See V3.1 FLEXFORM, Modul S_0, for the values, desc tions, and units of the assigned b and r paramet

$$b_{34} = \begin{cases} b_{49} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{50} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{51} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{52} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{35} = \begin{cases} b_{53} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{54} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{55} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{56} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{36} = \begin{cases} b_{63} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{64} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{65} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{66} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

R Parameters

$$[r_1, \ldots, r_6] = \begin{cases} [b_1, \ldots, b_6] & \text{in } S_0\text{, respectively, for } z_3 = 1 \\ [b_7, \ldots, b_{12}] & \text{in } S_0\text{, respectively, for } z_3 = 2 \\ [b_{13}, \ldots, b_{18}] & \text{in } S_0\text{, respectively, for } z_3 = 3 \\ [b_{19}, \ldots, b_{24}] & \text{in } S_0\text{, respectively, for } z_3 = 4 \end{cases}$$

$$[r_7, \ldots, r_{12}] = \begin{cases} [b_{25}, \ldots, b_{30}] & \text{in } S_0\text{, respectively, for } z_3 = 1 \\ [b_{31}, \ldots, b_{36}] & \text{in } S_0\text{, respectively, for } z_3 = 2 \\ [b_{37}, \ldots, b_{42}] & \text{in } S_0\text{, respectively, for } z_3 = 3 \\ [b_{43}, \ldots, b_{48}] & \text{in } S_0\text{, respectively, for } z_3 = 4 \end{cases}$$

$$[r_{13}, \ldots, r_{18}] = \begin{cases} [r_1, \ldots, r_6] & \text{in } S_0\text{, respectively, for } z_4 = 1 \\ [r_7, \ldots, r_{12}] & \text{in } S_0\text{, respectively, for } z_4 = 2 \end{cases}$$

3. G Functions

$g_1, \ldots, g_{19}$ are the same as in model Version 2.2, except that g_2 and the portion of g_{10} accounting for occasion 10(k=9) have moved to the upper module and the following substitution have been made:

Version 2.2	Version 3.1, S_1
b_{31}	z_1
b_{32}	z_2
b_{29}	z_3

Because processing in this module takes place using the lower level, k is replaced by k' in all of the g functio

4. F Functions[16/]

Functional Form and Description		Units
$f_{1,1} = 10(g_1 - g_4)$		g
$f_{1,2} = 10g_3$	See state variables,	g
$f_{2,2} = -10g_5$	X List, for description	g
$f_{3,3} = 10g_{11}$	by corresponding indexes.	number
$f_{4,4} = 10g_{13}$		mg

---

5. Y Functions

$y_i = x_i$, $i = 1, 2, 3$ See X list for description and units.

---

6. Special Functions

The special functions UV1 and UV2 are the same as those used in Version 2.2 except that k in the call string has been replaced by k'.

PARAMETERS

For values and definitions, see Version 2.2 FLEXFORM.

7. B Parameters

List	Description
$b_1, \ldots, b_6$	Carried in S_0 and assigned as a variable input.
$b_7, \ldots, b_{12}$	As in Version 2.2 FLEXFORM.
$b_{13}, \ldots, b_{18}$	
$b_{19}, \ldots, b_{30}$	
b_{24}, b_{25}, b_{36}	

8. R Parameters

$$\left.\begin{array}{l} r_1, \ldots, r_6 \\ r_7, \ldots, r_{12} \\ r_{13}, \ldots, r_{18} \end{array}\right\} \quad \text{Carried in } S_0 \text{ and assigned as a variable input.}$$

---

9. Initial Conditions

See appendix C for an example of the specification of initial conditions.

GENERAL RUN INFORMATION

Module Sequence Number = 1.

TMAX = 1 q = 10 TARGET

Module type: terminal.

Variables to be monitored: y_1, y_2, y_3. Resolution: 1.

Variables to be dump filed: y_1, y_2, y_3. Resolution: 1.

FILE NAMES

FLEX2 function overlay name: *V31S1.

Source File name: V31S1.

COMMENTS

Model behavior will be documented in a separate paper. A reco of the model runs made in studying behavior will be included therei Appendix A contains the source code for version 3.1 and the command file for beginning a simulation. Appendix C contains the inputs and outputs from a verification simulation.

LOGICAL UNIT MANIPULATION BY USER-SPECIFIED FUNCTIONS

The DFTM stand-outbreak model, V3.1, makes extensive utilization of ogical units (LUNs) in storing various vector values and in producing pecially formatted output tables. Much of the information concerning hese LUNs is summarized in table 4 and figure 4. This section details he information stored on some of the LUNs and the user specified unctions that produce that information.

Table 4. Logical units: assignment list
Note: All LUNs are equipped as linear access files except LUN 25, which is a random access file.

Logical Unit Number (LUN)	Description	Data Format
1	Phase I initial conditions	(I2, 7F11.5, I3)
2	Phase I outputs	(3F12.6)
3	Phase I redistributed insects	(1F12.6)
4	Phase II initial conditions	(I2, 7F11.5, I3)
5	Phase II outputs	(3F12.6)
6	Phase II redistributed insects	(IF12.6)
7	Phase III initial conditions	(I2, 7F11.5, I3)
8	Phase III outputs	(3F12.6)
9	Phase III redistributed insects	(1F12.6)
10	Phase IV initial conditions	(I2, 7F11.5, I3)
11	Phase IV outputs	(3F12.6)
12	Phase IV redistributed insects	(1F12.6)
13	Mortality and top-kill for Douglas-fir host species	(1F7.4, 6F6.3)
14	Mortality and top-kill for grand fir	(1F7.4, 6F6.3)
15	*Table* 1: Insect-foliage outbreak summary	variable BCD
16	*Table* 2: Foliage-stand outbreak summary	variable BCD
17	*Table* 3: Simulation run model parameterization	variable BCD
18	Screen display format of *table* 1	variable BCD
19	Scratch pad for temporary storage of module S_0 function g_3 output values ($\hat{g}_3$.)	(1F12.6)
20	*Table* 4: (optional) detail output of state variables during each phase	variable BCD
21	State variable values at each occasion for each tree class and phase in a simulation	(4(2X, F14.7))
22	Screen display format of *table* 2: part I	variable BCD
23	Screen display format of *table* 2: part II	variable BCD
24	Screen display format of *table* 2: part II	variable BCD
25	State-variable values: input	binary

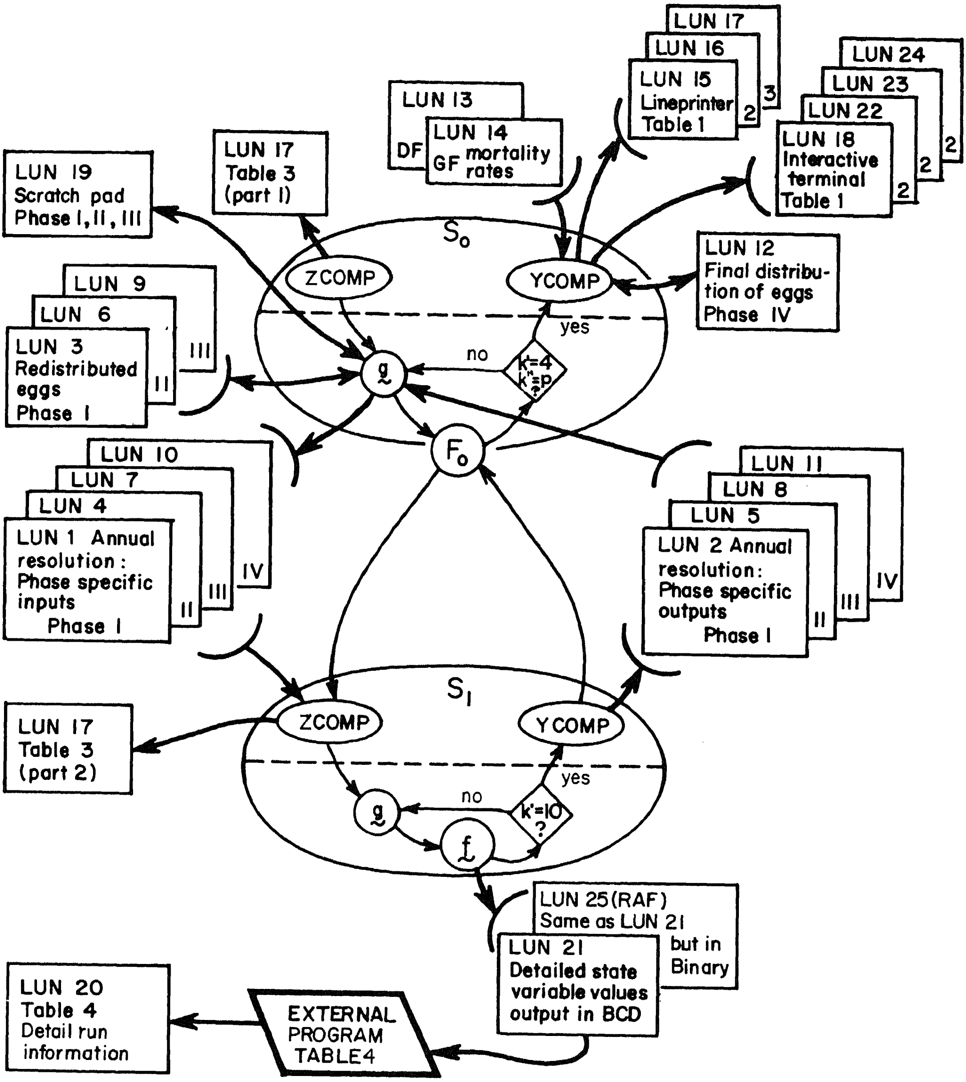

Figure 4.--Stand-outbreak model, Version 3.1: LUN assignment and identity.

LUNs 1, 4, 7, and 10 contain phase-specific initial condition information for phases I, II, III, and IV, respectively. The variabl identity, by record on the LUN, is:

$$z_{6j}, z_{4j}, z_{5j}, z_{2j}, z_{3j}, x_{5j}, x_{6j}, x_{7j}, j$$

where j is the tree-class identification index, and all variables are those of module S_0.

LUNs 2, 5, 8, and 11 contain phase-specific output conditions fr phases I, II, III, and IV, respectively. The variable identity is:

rocess. The variable identity is:

$$g_{2j}$$

rom module S_0.

LUN 19 is used as a "scratch" pad and stores the values $\hat{g}_{3\underset{\sim}{\cdot}}$ of odule S_0 for each phase, with each successive phase-specific output ector written over the previous vector.

Information is read from and/or written on the LUNs in the followi rder as a simulation run proceeds (see fig. 3):

1) Module S_0:

Z Functions: ZCOMP[17/] calls special function TABLE31.

Subroutine TABLE31

This subroutine writes most of *table* 3[18/] on LUN 17. The paramete hat are local to the lower module S_1 are written from that module.

G Functions: LUN 1 has been constructed before the simulation anc ontains the initial conditions for phase I. Only g_1 returns a value a his time, the other g functions produce no (zero) outputs at k' = 0.

2) Module S_0 (phase I):

Z Functions: ZCOMP, on the initial entry only, makes a call to th pecial function TABLE32.

Subroutine TABLE32

This subroutine writes the portion of *table* 3 that contains the estruction/consumption ratios and the larval growth rates on LUN 17.

F Functions: Function $f_{4,4}$ makes a call to special function S_2.

Subroutine S2($\underset{\sim}{b}$)

This subroutine writes the value of each state variable for each ccasion (k') on a random access file, LUN 25, in binary and a duplicat utput on LUN 21 in BCD. The material on LUN 25 is then available for ccess by an external program TABLE4 that will produce detailed infor- ation on any state variable at any occasion for each tree class during simulation; this is produced as output *table* 4 on LUN 20.

[17/] Two special-purpose standard FLEX subroutines, ZCOMP and YCOMP, are ssociated with each module in a model. ZCOMP is processed first and YCOMP ast in each time step. ZCOMP handles all input-variable processing, and COMP handles all output-variable processing.

[18/] To distinguish computer output tables from the tables in this paper, he computer output tables will be written in italics, *table*. Subroutines ar iven in all cap., e.g., TABLE32.

Y Functions: YCOMP[19] writes the values of y_1, y_2, and y_3 on LU
These are the year-end values of the variables, that is the phase-specific population-branch model outputs.

Module S_1 is processed once for each tree class with no calculati of any g function values in module S_0 during this processing.

(3) Module S_0:

G Functions: Function g_2, through special function REDIST, writ the values $\hat{\underset{\sim}{g}}_{2.}$ on LUN 3.

Function g_3 writes the values $\hat{\underset{\sim}{g}}_{3.}$ on LUN 19.

Function g_4, utilizing the information on LUNs 1, 2, 3, and 19, writes new values on LUN 4, where $\underset{\sim}{x}_5$ is replaced by the tree class specific values of y_1 from LUN 2, $\underset{\sim}{x}_6$ is replaced by $\hat{\underset{\sim}{g}}_{3.}$ from LUN 19 ar $\underset{\sim}{x}_7$ is replaced by the values $\hat{\underset{\sim}{g}}_{4.}$ produced by this function. LUN 4 nov contains the initial conditions for phase II. The replacement done b this function constitutues the updating of variables $\underset{\sim}{x}_5$, $\underset{\sim}{x}_6$, and $\underset{\sim}{x}_7$; this is normally an automatic part of the FLEX algorithm, but because of the vector manipulations occurring in this module, the updating mu be done by a user-defined function (see Vector Processing in FLEX2).

All other values are simply transferred unchanged from LUN 1 to LUN 4.

(4) Module S_1 (phase II):

F Functions: Function $f_{4,4}$ makes a call to special function S2.

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN 5

Module S_1 is processed once for each tree class with no calculat of g function values in S_0.

(5) Module S_0:

G Functions: Function g_2 writes the values $\hat{\underset{\sim}{g}}_{2.}$ on LUN 6.

Function g_3 writes the values $\hat{\underset{\sim}{g}}_{3.}$ on LUN 19.

Parallel to what is done in (3) above, function g_4 writes the values $\hat{\underset{\sim}{g}}_{4.}$ on LUN 7, as well as transferring other appropriate inform tion from LUNs 4, 5, 6, and 19 to LUN 7. LUN 7 contains phase-III initial conditions.

---

[19] Refer to footnote 17 on previous page.

F Functions: Function $f_{4,4}$ makes a call to special function S2

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN

Module S_1 is processed once for each tree class with no calcula of g function values in S_0.

(7) Module S_0:

G Functions: Function g_2 writes the values $\underset{\sim}{\hat{g}}_{2\cdot}$ on LUN 9.

Function g_3 writes the values $\underset{\sim}{\hat{g}}_{3\cdot}$ on LUN 19.

Function g_4 writes the values $\underset{\sim}{\hat{g}}_{4\cdot}$ on LUN 10, as well as transferring other appropriate information from LUNs 7, 8, 9, and 19 to L LUN 10 contains phase-IV initial conditions.

(8) Module S_1 (phase IV):

F Functions: Function $f_{4,4}$ makes a call to special function S2

Y Functions: YCOMP writes the values of y_1, y_2, and y_3 on LUN

Module S_1 is processed once for each tree class with no calcula of g function values in S_0.

(9) Module S_0:

Y Functions: YCOMP calls REDIST for computation of the mean fa egg density over the stand after phase IV. REDIST then computes the redistributed egg density for each tree class and writes them as $\underset{\sim}{x}_7$ LUN 12.

YCOMP then calls the special function subroutines TABLE33 and TABLE12 to complete *table* 3 and produce the output tables 1 and 2.

Subroutine TABLE33

This subroutine completes *table* 3 on LUN 17 by writing the fall mean egg density per model branch over the stand for each phase.

Subroutine TABLE12

This subroutine produces the annual input-output summary of the model branch for each phase and tree class as *table* 1 on LUN 15. It also determines the postoutbreak probabilities of primary and second mortality, probabilities of degrees of top-kill, height- and diamete growth reduction factors for each tree class, all according to the classification structure provided by Boyd Wickman (1963, 1978a, 1978 ion structure are stored on and input to this subroutine from LUNs 1 nd 14. This information is used in producing outbreak impacts as *tab* n LUN 16.

Additionally, *table* 1 is output on LUN 18 in a format suitable fo iewing from an interactive terminal screen. This is done for *table* 2 s well, but with the requirement of outputting it in three parts on UNs 22, 23, and 24.

STAND-POSTOUTBREAK MODEL

The stand-postoutbreak model is the filter that takes the defoli- tion history from an outbreak simulation and associates with defoli- tion for each tree class the expectations of: direct and secondary ortality; degrees of top-kill; and radial- and height-growth impacts.

The development of the mortality and top-kill expectations are ased on the history of host tree plots associated with the DFTM out- reak of 1972-1974 in eastern Oregon (Wickman 1978b). The model branc efoliation is translated into crown defoliation via the branch-tree elationship.

For each tree class, branch defoliation is converted into crown efoliation using the logistic equation

$$y = \frac{p_1}{p_2 + p_3 e^{p_1 x}}$$

vhere for $x,y \varepsilon [0.1]$:

x: model branch defoliation as a proportion of nominal.

y: proportion of crown totally defoliated.

$p_1 = -22.579678$

$p_2 = -22.996253$

$p_3 = -598,181,961.$

hese parameters were obtained by nonlinear least squares curve fit t eans of data from the six crown-defoliation classes of Wickman (1978 rown defoliation determines one of seven possible effects vectors. ector is used to partition the trees of the tree class into direct a econdary mortality or a range of top-kill and growth loss. The set ectors that determine these losses is derived from the input files ead from LUNs 13 and 14 given in appendix C. The same algorithm is

for each host specific file. The information on these files is structu
as follows: the first seven contain direct mortality and top-kill information; the remaining two contain secondary mortality information. Letting A(i,j) be the jth entry from the ith row, one has the following correspondences: For i =

1: all parameters correspond to trees (a tree class) with less than 15% of the crown totally defoliated,

2: all parameters correspond to trees with between 15% and of the crown totally defoliated,

3: parameters for trees with between 35% and 65% of the cro totally defoliated,

4: parameters for trees with between 65% and 85% of the cro totally defoliated,

5: parameters for trees with between 85% and 95% of the cro totally defoliated,

6: parameters for trees with between 95% and 99.5% of the crown totally defoliated,

7: parameters for trees with greater than 99.5% of the crown totally defoliated,

and for each of the above values of i, the following definitions are given of A(i,j) for j =

1: expected proportion of trees for which mortality is directly attributable to defoliation,

2: expected proportion of trees with no top-kill damage,

3: expected proportion of trees with leader-kill, 1 year's growth only,

4: expected proportion of trees with top-kill less than 10%

5: expected proportion of trees with top-kill less than 25%

6: expected proportion of trees with top-kill less than 50%

7: expected proportion of trees with some top-kill,

8: expected loss in diameter growth from defoliation.

The last two records in these files contain the information necessary to remove secondary mortality from the arrays described above. They are as follows: A(i,j) for i=

8: expectations of secondary mortality associated with bark beetle attack,

9: expectations of secondary mortality from all other causes, e.g., windthrow, winterkill, natural attrition, for j =

1: expectation for trees without top-kill,

2: expectation for trees with leader-kill only,

3: expectation for trees with more than leader-kill, but less than 10% top-kill,

4: expectation for trees with top-kill between 10% and 2

5: expectation for trees with top-kill between 25% and 5

6: expectation for trees with top-kill greater than 50%.

Because the top-kill information on the external files is cumulative ferences are taken between successive classes to get the number for interval. From the resulting classes, secondary mortality is ved after combining the two secondary mortality factors--that caused ark beetles and that caused by other factors such as windthrow, , fire, and other "unknown" causes.

The two forms of secondary mortality are assumed to act indepen- ly, hence the two vectors are combined by the rule:

$$(m_{1,j} + m_{2,j} - m_{1,j}m_{2,j}) = v_j.$$

scalar- or dot-product of this vector with the input vector of duals of direct mortality is then used to compute secondary mortality each defoliation class:

$$\sum_{j=2}^{6} v_j r_{i,j+1} = s_i,\ i=1, \ldots , 7.$$

$r_{i,j}$ is the vector of residuals (ith record of LUN 13 or LUN 14), s_i is the derived secondary mortality that will be used in *table* 2 imulation output (appendix C).

After secondary mortality has been subtracted from the residuals of ect mortality, the remaining numbers are the expected proportions are to receive various levels of top-kill, and one class that cates the proportion receiving only growth reductions.

Growth reductions attributable to defoliation are changes in eter growth at breast height and height growth. Growth reduction is nction of maximum model branch defoliation. These assumptions lt in the following table of possible effect vectors. One vector is en by species and defoliation.

An example of defoliation impact summaries is given in *table* 2 of output section of appendix C.

Output expectations of mortality and top-kill by tree defoliation

uglas-fir host:

Percent of crown totally defoliated	Direct mortality	Secondary mortality	Top-kill (total)	Growth impacts only	Expected top-kill Leader kill	 1-10% of crown	 10-25% of crown	 25-50% of crown	 50-90% of crown
0-15	0	.1127	.1129	.7744	.0675	.0454	0	0	0
16-35	0	.1229	.2081	.6690	.1360	.0696	0	0	.0026
36-65	.0090	.0927	.4032	.4951	.1744	.2058	0	.0230	0
66-85	.0280	.1000	.4820	.3900	.2376	.1606	0	.0838	0
86-95	.1730	.1950	.2929	.3391	.1400	.0607	0	.0782	.0140
96-99.5	.4770	.1070	.1864	.2296	.1422	.0359	0	0	.0083
99.5-100	.9230	.0158	.0274	.0338	.0209	.0053	0	0	.0012

Grand fir host:

Percent of crown totally defoliated	Direct mortality	Secondary mortality	Top-kill (total)	Growth impacts only	Expected top-kill Leader kill	 1-10% of crown	 10-25% of crown	 25-50% of crown	 50-90 of crown
0-15	0	.0451	.0544	.9005	.0331	.0123	.0039	.0029	.0022
16-35	0	.0422	.1261	.8316	.0877	.0294	.0068	.0019	.0004
36-65	.0090	.0455	.2674	.6781	.1322	.0882	.0317	.0113	.0039
66-85	.0280	.0592	.3817	.5311	.1723	.1022	.0424	.0480	.016
86-95	.1730	.0957	.3387	.3926	.1893	.0580	.0217	.0157	.054
96-99.5	.4770	.0790	.2137	.2302	.0963	.0401	.0274	0	.049
99.5-100	.9230	.0116	.0315	.0339	.0142	.0059	.0040	0	.007

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APPENDIX A VERSION 3.1 SOURCE CODE

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Command file 57

DFTM stand-outbreak model

Module S_0 58

Module S_1 61

Stand-postoutbreak model

Module S_0 65

Module S_1 73

Subroutine TABLE12 flowchart 74

```
EOD ON INPUT UNIT
00001 -MODULEGET()=1
00002 -NUMBER=7 Q=4 MODULETYPE=1 P=24
00003 -TMAX=1 FUNLOAD=*V31S0
00004 -YMAX=3 NODUMP NOLOG TTYOFF NOSUMMARY
00005 -TITLE= S(1) REVISED  STAND OUTBREAK  MODULE
00006 -B()=0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,
00007 -  0.001,0.001,0.002,0.003,0.006,0.013,0.035,0.028,0.025,0.02
00008 -0.031,0.034,0.035,0.035,0.0,0.0,0.0,0.0.0.0,0.0,
00009 -0.,0.,0.,0.,0.001,0.001.0.001,0.002,0.003,0.010,
00010 -0.016,0.042,0.005,0.006,0.007,0.021,0.033,0.056,0.5,0.62,
00011 -0.75,0.80,200.,200.,150.,150.,0.,0.50,0.60,0.85,
00012 -0.90,0.
00013 -R()= 1.0, 0.75, 0.1, 0., 0., 0., 1.0, 0.8, 0.5, 0.1,
00014 -  0., 0., 0.02, 0.02, 0.02, 0.02, 0.02, 0.02
00015 -MODULEGET()=1,1
00016 -NUMBER=4 Q=10 TARGET
00017 -TMAX=1 FUNLOAD=*V31S1
00018 -DUMPLUN=40
00019 -D=Y(1) C=Y(2) D=Y(3)
00020 -YMAX=3
00021 -LP=Y(1) LP=Y(2) LP=Y(3)
00022 -D=Y(1) C=Y(2) D=Y(3)
00023 -B()=.02,  .02,  .02,  .02,  .02,  .02,  5.4,  6.25, 6.25, 2
00024 -    2.27, 2.0,  5.4,  6.25, 6.25, 3.69, 3.29, 3.0, 1.19, .08
00025 -  0.10, .1147, .0886, .0625, .197, 52.0626838, .02,0.01,0.0,
00026 -TITLE=SIMULATION ON THE REVISED MODEL VERS. 3.
00027 -TTYOFF NOSUMMARY
00028 -MODULEGET()=1
00029 -FIRSTSUB()=1,1
00030 -MODULEGET()=1,1
00031 -GHOST()=1
00032 -INPUT=60
EOF ON INPUT UNIT
```

```
C
      SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
      DIMENSION X(1),B(1),R(1),Z(1),G(1)
      WRITE(61,2000)
 2000 FORMAT(≠ ENTER NUMBER OF TREE CLASSES IN STAND≠)
      Z(1)=FFIN(60)
      B(57)=Z(1)
C
C *** WRITE THE BEGINNING OF TABLE 3 ***
C
      CALL TABLE31(B,R)
      RETURN
      END
C
C
C
C
C
      FUNCTION G01(K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G01=FLOAT(KP+1)
      RETURN
      END
C
C
      FUNCTION G02 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G02=0.
      IF (KP.EQ.IPHASE) RETURN
      IF (KP.EQ.0) RETURN
      INUM=IFIX(B(57))
      CALL REDIST(KP,INUM,B,X)
      IPHASE=KP
      RETURN
      END
C
C
      FUNCTION G03(K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G03=0.
      IP=KP+1
      IF (IP.EQ.IPHASE) RETURN
      IF(KP.EQ.0) RETURN
      NN=IFIX(Z(1))
      LUN=(IP-2)*3
      LUN1=LUN+1
      LUN2=LUN+2
      LUN19=19
      REWIND LUN1
      REWIND LUN2
      REWIND LUN19
      DO 10 J=1,NN
      READ(LUN1,1000) Z2,Z3
 1000 FORMAT(24X,2F11.5)
      READ(LUN2,1001) X6
 1001 FORMAT(12X,1F12.6)
      G3=FMIN((1.-Z2/100)*Z3,X6)
      WRITE(LUN19,1002) G3
 1002 FORMAT(1F12.6)
 10   CONTINUE
      IPHASE=IP
      RETURN
      END
C
C
      FUNCTION G04(K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G04=0.
      IP=KP+1
      IF (IP.EQ.IPHASE) RETURN
      IF (KP.EQ.0) RETURN
      NN=IFIX(Z(1))
      LUN=(IP-2)*3
      LUN1=LUN+1
      LUN2=LUN+2
      LUN3=LUN+3
      LUN4=LUN+4
      LUN19=19
      REWIND LUN2
      REWIND LUN3
      REWIND LUN4
      REWIND LUN19
      DO 120 I=1,NN
      READ (LUN1,2000) IZ6,Z4,Z5,Z2,Z3,J
 2000 FORMAT (1I2,4F11.5,33X,1I3)
      READ (LUN2,2200) X5
      READ (LUN3,2200) G2
      READ (LUN19,2200) G3
 2200 FORMAT (1F12.6)
      IPP=IP+56
      X7=(1.-B(IPP))*G2
      X6=G3
  120 WRITE(LUN4,2300) IZ6,Z4,Z5,Z2,Z3,X5,X6,X7,J
 2300 FORMAT (1I2,7F11.5,1I3)
      REWIND LUN4
      IPHASE=IP
      RETURN
      END
C
C
      SUBROUTINE YCOMP(K,X,B,R,Y,XS,T)
      DIMENSION X(1),B(1),R(1),Y(1),XS(1)
      KP=4
      IB57=IFIX(B(57))
      CALL REDIST(KP,IB57,B,X)
C
C  ***      FINISH TABLE 3, ON LUN 17        ***
C
      CALL TABLE33(X,B)
C
C  ***      WRITE TABLES 1 AND 2       ***
C
      CALL TABLE12(B)
      RETURN
      END
C
C
      SUBROUTINE REDIST(KP,INUM,B,X)
      DIMENSION B(1),X(1),XYCOMP(4)
C
C           INITIALIZE LUN VALUES AND REWIND
C
      LUN1=(KP-1)*3+1
      LUN2=(KP-1)*3+2
      LUN3=(KP-1)*3+3
      REWIND LUN1
      REWIND LUN2
C
C  ***                 REDISTRIBUTION OF EGGS            ***
C           INITIALIZE LOCAL VARIABLES
C
      SUM=TOTSTEM=0.0
C
C           CALCULATE TOTAL EGGS OVER STAND (SUM)
C           AND TOTAL WEIGHTED SUM OF TREES(TOTSTEM)
C
      DO 10 J=1,INUM
      READ(LUN1,1001) Z4,Z5
 1001 FORMAT(2X,2F11.5)
      READ (LUN2,1000) X7
 1000 FORMAT (24X,F12.6)
      SUM=SUM+X7*Z4*Z5
      TOTSTEM=TOTSTEM+Z4*Z5
   10 CONTINUE
C
C           CALCULATE X(KP) WHERE KP IS PREVIOUS PHASE
C           STORE LOCALLY IN XYCOMP(KP) UNTIL PHASE IV
C           TO PREVENT XS=0 FROM ERASING STORED VALUES
C
      XYCOMP(KP)=SUM/TOTSTEM
      REWIND LUN2
C
C           CALCULATE VALUES OF G(2,J) FOR S0 HERE,
C           INSTEAD OF IN FUNCTION G02 CODE AND WRITE ON LUN
C
      DO 20 J=1,INUM
 -        READ (LUN2,1000) X7
 -        G2=X7+B(62)*(XYCOMP(KP)-X7)
 -        WRITE (LUN3,1010) G2
 -  1010  FORMAT(F12.6)
 -  20    CONTINUE
 -        IF(KP.EQ.4) GO TO 25
 -        RETURN
 -C
 -C               TRANSFER VALUES FROM LOCAL STORAGE TO X ARRAY
 -C
 -     25 DO 30 I=1,4
 -        X(I)=XYCOMP(I)
 -  30    CONTINUE
 -        RETURN
 -        END
N INPUT UNIT
```

```
C                FLEX FUNCTIONS FOR V3.1 DFIM MODULE S(1)
C
C
      SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
      DIMENSION X(1),B(1),R(1),Z(1),G(1)
C
C***    READ IN THE Z VECTOR, INITIAL X VECTOR    ***
C
      CALL VARIN (Z(3),G(1))
      IP=IFIX (Z(3))
      LUN1=(IP-1)*3+1
      READ (LUN1,1000) ISPECIES,Z(1),Z(2),X(1),X(2),X(3)
 1000 FORMAT (1I2,22X,5F11.5)
      Z(4)=FLOAT(ISPECIES)
      X(4)=0.0
C
C *** SET PHASE-SPECIFIC PARAMETERS B(29) AND B(34--36)
C
      B(29)=Z(3)
      CALL VARIN(B(34),B(IP+48))
      CALL VARIN (B(35),B(IP+52))
      CALL VARIN (B(36),B(IP+62))
C
C***     READ IN HOST AND PHASE SPECIFIC MORTALITY VECTORS
C
      DO 6 J=1,6
      I1=J+(IP-1)*6
      I2=J+(IP+3)*6
      I3=J+(ISPECIES-1)*6
      CALL VARIN (B(J),R(J+12))
      CALL VARIN (R(J),B(I1))
      CALL VARIN (R(J+6),B(I2))
    6 CALL VARIN (R(J+12),R(I3))
      IF (K.NE.0) RETURN
C
C *** FINISH TABLE 3 ON LUN 17 ***
C
      CALL TABLE32(B)
      RETURN
      END
C
C
C
C
C
      FUNCTION G01 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G01=0.
      IF(KP.EQ.8) G01=(Z(2)*Z(1)/100.)*((X(1)+X(2)+Z(2))/
     A  (2.0*Z(2))-G(19)*B(27))
      RETURN
      END
C
C
      FUNCTION G03 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G03=0.0
      IF (KP.EQ.8) G03=X(1)
      RETURN
      END
C
C
      FUNCTION G04 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G04=0.0
      IF (KP.GT.0.AND.KP.LE.6)G04=FMIN(G(16),X(1))
      RETURN
      END
C
C
      FUNCTION G05 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G05=0.0
      IF (KP.GE.1.AND.KP.LE.6) G05=FMIN(G(18),X(2))
      RETURN
      END
C
C
```

```
      G06=0.
      IF(KP.GT.0.AND.KP.LE.6) G06=(1.-R(KP))*(1.-R(KP+6))*(1.-R
      RETURN
      END
C
C
      FUNCTION G07 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G07=0.
      IF(KP.GT.0.AND.KP.LE.6) G07=1.-R(KP+12)
      RETURN
      END
C
C
      FUNCTION G08 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G08=0.
      IF (KP.EQ.0.OR.KP.GT.6) RETURN
      G08=G(6)**10.-1.
      IF(G(15).NE.10..AND.G(7).NE.0.)G08=(G(6)**10.)*(G(7)**(10
     C-G(15)))-1.
      IF (G(7).EQ.0..AND.G(15).NE.10.) G08=-1.
      RETURN
      END
C
C
      FUNCTION G09 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      IF(KP.EQ.0.OR.KP.EQ.9) GTOT=0.
      GTOT=GTOT+G(17)
      G09=GTOT
      RETURN
      END
C
C
      FUNCTION G10 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G10=0.
      IF(KP.EQ.0)G10=-B(36)
      IF(KP.EQ.5) G10=-(1.+G(8))*B(30)
      IF(KP.EQ.7) G10=-B(34)
      IF(KP.EQ.8) G10=(B(35)*G(14)*(1.0-B(28)*G(9))-1.0)
      RETURN
      END
C
C
      FUNCTION G11 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G11=(G(8)+G(10))*X(3)
      RETURN
      END
C
C

      FUNCTION G12 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G12=0.
      IF(X(3).LE.0..OR.X(1)+X(2).LE.0.) GO TO 10
      IF(KP.GE.1.AND.KP.LT.4) G12=B(22)
      IF(KP.EQ.4) G12=B(23)
      IF(KP.GT.4.AND.KP.LE.6) G12=B(24)
   10 RETURN
      END
C
C
      FUNCTION G13 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G13=0.
      IF(KP.EQ.0) G13=B(25)
      PHI=(G(4)+G(5))/(G(4)+G(18))
      IF(KP.GT.0.AND.KP.LE.6) G13=X(4)*(EXP(10.*G(12)*PHI)-1.)
      RETURN
      END
C
C
      FUNCTION G14 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G14=FMAX(2.*X(4)/B(26)-1.,0.)
      RETURN
      END
```

```
C
C
      FUNCTION G15 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      IF(KP.EQ.0.OR.KP.GT.6) GO TO 15
      DO 10 I=0,10
      ALPHA=FLOAT(10-I)
      G15=ALPHA
      IF(UV1(KP,X,B,ALPHA).LT.X(1)) RETURN
   10 CONTINUE
      RETURN
   15 G15=0.
      RETURN
      END
C
C
      FUNCTION G16 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G16=0.
      IF(KP.EQ.0.OR.KP.GT.6)RETURN
      ALPHA=FMIN(G(15)+1.,10.)
      IF(X(1).GT.0.0)G16=UV1(KP,X,B,ALPHA)
      RETURN
      END
C
C
      FUNCTION G17 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      IF(KP.EQ.0.OR.KP.GT.6) GO TO 20
      G17=10.-G(15)
      ALPHA=G(15)
      N=IFIX(10.-G(15))
      DO 10 I=0,N
      ETA=FLOAT(I)
      ETAPLUS=ETA+1.
      IF((UV2(KP,X,B,ALPHA,ETAPLUS)-(X(1)-UV1(KP,X,B,ALPHA)))
     C.GT.X(2)) GO TO 15
   10 CONTINUE
      RETURN
   15 G17=ETA
      RETURN
   20 G17=0.
      RETURN
      END
C
C
      FUNCTION G18 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      G18=0.
      IF (KP.EQ.0.OR.KP.GT.6) RETURN
      ALPHA=G(15)
      ETA=10.-ALPHA
      G18=UV2(KP,X,B,ALPHA,ETA)-(X(1)-UV1(KP,X,B,ALPHA))
      IF (G18.LT.0.) G18=0.
      RETURN
      END
C
C
      FUNCTION G19 (K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      IF(KP.EQ.0.OR.KP.EQ.9) GTOT=0.
      IF(KP.GT.0.AND.KP.LE.6)GTOT=GTOT+(10.-(G(15)+G(17)))
      G19=GTOT
      RETURN
      END
C
C
      FUNCTION F0101(K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      F0101=10.0*(G(1)-G(4))
      RETURN
      END
C
C
      FUNCTION F0102(K,X,B,R,Z,KP)
      DIMENSION X(1),B(1),R(1),Z(1)
      F0102=10.0*G(3)
      RETURN
      END
C
C
```

```
-       FUNCTION F0202(K,X,B,R,Z,KP)
-       DIMENSION X(1),B(1),R(1),Z(1)
-       F0202=10.0*(-G(5))
-       RETURN
-       END
-C
-C
-       FUNCTION F0303(K,X,B,R,Z,KP)
-       DIMENSION X(1),B(1),R(1),Z(1)
-       F0303=10.0*G(11)
-       RETURN
-       END
-C
-C
-       FUNCTION F0404 (K,X,B,R,Z,KP)
-       DIMENSION X(1),B(1),R(1),Z(1)
-       F0404=G(13)*10.0
-       CALL S2(X,KP,F0404)
-       RETURN
-       END
-C
-C
-C
-C
-C
-       SUBROUTINE YCOMP (K,X,B,R,Y,XS,T)
-       DIMENSION X(1),B(1),R(1),Y(1)
-       DO 10 I=1,3
-    10 Y(I)=X(I)
-       IF (K.EQ.0) RETURN
-       IP=IFIX(B(29))
-       LUN2=(IP-1)*3+2
-       WRITE (LUN2,1000) Y(1),Y(2),Y(3)
-  1000 FORMAT (3F12.6)
-       RETURN
-       END
-C
-C
-       FUNCTION UV1 (KP,X,B,ALPHA)
-       DIMENSION X(1),B(1)
-       UV1=0.
-       IF(KP.EQ.0.OR.KP.GT.6) RETURN
-       U=X(3)*X(4)
-       I=KP+6
-       UV1=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
-      C(1.-(G(6)*EXP(G(12)))**ALPHA)/(1.-G(6)*EXP(G(12)))
-       RETURN
-       END
-C
-C
-       FUNCTION UV2 (KP,X,B,ALPHA,ETA)
-       DIMENSION X(1),B(1)
-       UV2=0.
-       IF(KP.EQ.0.OR.KP.GT.6) RETURN
-       U=X(3)*X(4)
-       I=KP+12
-       IF(G(7).EQ.0..AND.ETA.EQ.0.) RETURN
-       UV2=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
-      CG(6)**ALPHA*EXP(ALPHA*G(12))*(1.-(G(6)*G(7)*EXP(G(12)))**ETA)
-      C(1.-G(6)*G(7)*EXP(G(12)))
-       RETURN
-       END
  INPUT UNIT
```

```
      SUBROUTINE TABLE3(B,R)
      DIMENSION B(1),R(1)
C
C          BEGIN TABLE 3 ON LUN 17
C          OBTAIN TIME AND DATE
C
      TIME=0.
      DATE=0.
      EM=0.
      CALL XREQ (33B,0,0,EM,TIME)
      CALL XREQ (32B,0,0,EM,DATE)
C
C          WRITE HEADING ON LUN 17
C
      WRITE (17,1000) TIME,DATE
C
 1000 FORMAT(≠1≠,/≠-≠,/≠-≠,9X,≠TABLE 3:  PARAMETERS FOR 
     C,≠ OUTBREAK:≠,
     C≠ MORTALITY, FOLIAGE DESTRUCTION, AND OTHER.≠
     C,14X,2(2X,A8)/≠0≠,19X,
     C≠HOST TREE, STAND, PHASE, OR INSTAR SPECIFIC.≠/≠-≠
     C≠DESCRIPTION≠,9X,≠PHASE≠,5X,≠SPECIES≠,21X,≠INSTAR≠
     C≠PUPAE≠,5X,≠OVERWINTER≠,6X,≠EGG MASS≠/≠ ≠,52X,≠1≠,
     C6X,≠3≠,6X,≠4≠,6X,≠5≠,6X,≠6≠,9X,≠MORTALITY   MORTALI
     C 9X,≠SIZE≠/≠ ≠,
     C135(≠-≠)/≠0   DAILY MORTALITY RATE≠/≠  ≠,24(≠-≠))
C
C          WRITE BACKGROUND DAILY MORTALTTY RATES
C
      WRITE (17,1010) (R(J),J=13,18)
 1010 FORMAT(≠0≠,9X,≠BACKGROUND≠,8X,≠I,II,III,IV DF,GF≠,
     C6(1X,F5.3,1X))
C
C          WRITE DAILY DISEASE MORTALITY RATES
C          PHASES I, II, III, IV
C
      WRITE(17,1020) (B(J),J=1,6)
 1020 FORMAT(≠0≠,9X,≠DISEASE≠,15X,≠I≠,7X,≠DF,GF≠,5X,6(1X,
      WRITE (17,1030) (B(J),J=7,12)
 1030 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
      WRITE(17,1040) (B(J),J=13,18)
 1040 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,5X,6(1X,F5.3,1X))
      WRITE (17,1045) (B(J),J=19,24)
1045  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,5X,6(1X,F5.3,1X))
C
C          WRITE DAILY PARASTTE/PREDATOR MORTALITY RATES
C          PHASES I, II, III, IV
C
      WRITE (17,1050) (B(J),J=25,30)
 1050 FORMAT(≠0≠,9X,≠PARASITE/PREDATOR≠,5X,≠I≠,7X,≠DF,GF
    1          6(1X,1F5.3,1X))
      WRITE(17,1060) (B(J),J=31,36)
 1060 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF, GF≠,5X,6(1X,F5.3,1X))
      WRITE (17,1070) (B(J),J=37, 42)
 1070 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,5X,6(1X,F5.3,1X))
      WRITE (17,1075) (B(J),J=43,48)
1075  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,5X,6(1X,1F5.3,1X))
C
C          WRITE HOST-SPECIFIC DAILY STRESS MORTALITY RAT
C          PHASES I, II, III, IV
C
      WRITE(17,1080) (R(J),J=1,6)
 1080 FORMAT(≠0≠,9X,≠STRESS≠,12X,≠I,II,III,IV≠,2X,≠DF≠,7X
      WRITE (17,1090) (R(J),J=7,12)
 1090 FORMAT(≠ ≠,27X,≠I,II,III,IV≠,2X,≠GF≠,7X,6(X,F5.3,X
C
C          WRITE SUB-HEADING
C
      WRITE  (17,1095)
 1095 FORMAT(≠  ≠,24(≠-≠)/≠0 OCCASION MORTALITY RATE≠/≠
C
C          WRITE PUPATION MORTALITY RATES
C          PHASES I, II, III, IV
C
      WRITE(17,1100) B(49)
 1100 FORMAT(≠0≠,10X,≠PUPAE≠,16X,≠I≠,7X,≠DF,GF≠,55X,F5.3
      WRITE (17,1110) B(50)
 1110 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,55X,F5.3)
      WRITE(17,1120) B(51)
 1120 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,55X,F5.3)
      WRITE (17,1125) B(52)
1125  FORMAT (≠ ≠,30X,≠IV≠,7X,≠DF,GF≠,55X,1F5.3)
C
C               WRITE OVERWINTER EGG MORTALITY RATES
C               AFTER PHASES I, II, III, IV
C
      WRITE (17,1130) B(58)
 1130 FORMAT(≠0≠,9X,≠OVERWINTER≠,9X,≠I - II≠,5X,≠DF,GF≠,67X,F
      WRITE(17,1140) B(59)
 1140 FORMAT(≠ ≠,27X,≠II - III≠,4X,≠DF,GF≠,67X,F5.3)
      WRITE (17,1150) B(60)
 1150 FORMAT(≠ ≠,27X,≠III - IV     DF,GF≠,67X,F5.3)
      WRITE (17,1155) B(61)
1155  FORMAT (≠ ≠,27X,≠IV-      ≠,5X,≠DF,GF≠,67X,1F5.3)
C
C               WRITE NOMINAL EGG MASS SIZE
C               PHASES I, II, III, IV
C
      WRITE(17,1160) B(53)
 1160 FORMAT(≠  ≠,24(≠-≠)/≠0  NOMINAL EGG MASS SIZE≠, 8X,
     C≠I≠,7X,≠DF,GF≠,82X,F5.1)
      WRITE (17,1170) B(54)
 1170 FORMAT(≠ ≠,30X,≠II≠,7X,≠DF,GF≠,82X,F5.1)
      WRITE(17,1180) B(55)
 1180 FORMAT(≠ ≠,30X,≠III≠,6X,≠DF,GF≠,82X,F5.1)
      WRITE (17,1190) B(56)
1190  FORMAT (31X,≠IV≠,7X,≠DF,GF≠,82X,1F5.1)
      RETURN
      END
EOD ON INPUT UNIT
      SUBROUTINE TABLE33(X,B)
      DIMENSION X(1),B(1)
C
C               COMPLETE TABLE 3 BY WRITING THE PHASE-SPECIFIC MEA
C               EGG DENSITIES FOR PHASES I, II, III, IV, AND THE
C               AND THE OUTBREAK REDISTRIBUTION COEFFICIENT
C
      WRITE(17,3000) (X(I),I=1,4)
 3000 FORMAT(≠0≠,135(≠-≠)/≠- PHASE SPECIFIC≠,
     C≠ MEAN EGG DENSITIES:    I=≠,F7.3,≠    II=≠,F7.3,
     C≠    III=≠,F7.3,≠    IV=≠,1F7.3)
      WRITE (17,2999) B(62)
 2999 FORMAT (≠0REDISTRIBUTION COEFFICIENT FOR THE≠,
     C≠ OUTBREAK:  ≠,F7.3)
      RETURN
      END
EOD ON INPUT UNIT
      SUBROUTINE TABLE12(B)
C
C               THIS ROUTINE WRITES THE TWO SPECIALLY FORMATTED OU
C               SUMMARIES REFERRED TO AS TABLES 1 AND 2.
C               TABLE 1 GIVES THE INPUT/OUTPUT VARIABLE VALUES, BY
C               OVER THE COURSE OF THE OUTBREAK.  TABLE 2 CONDENSE
C               INFORMATION FURTHER AND GIVES THE MORTALITY AND TO
C               EXPECTIONS WHICH COMPRISE THE STAND POST-OUTBREAK
C
      DIMENSION B(1)
      DIMENSION ISPECIES(6),IC(15,3),A(15,26),C(15,5),AMORT(1
      DIMENSION WT(15)
      DIMENSION IPHASE(4),BB(2,12)
      DATA((IPHASE(I),I=1,4)=≠I    ≠,≠II   ≠,≠III  ≠,≠IV   ≠)
      DATA ((ISPECIES(I),I=1,6)=≠DOUG≠,≠LAS-≠,≠FIR ≠,≠ GRA≠,
     C ≠ND F≠,≠IR   ≠)
C
C               OBTAIN TIME AND DATE
C
      TIME=0.
      DATE=0.
      EM=0.
      CALL XREQ(33B,0,0,EM,TIME)
      CALL XREQ(32B,0,0,EM,DATE)
C
```

```
         AMORT(I,J) J=1,...,7, I=8,...,14 CONTAIN FIRST 7 RECORDS
         BB(I,J) J=7,...,12, I=1,2 CONTAIN LAST 2 RECORDS

         I VARIES WITH PERCENT OF CROWN DEFOLIATED:
          1 OR 8::0-15%: 2 OR 9::16-35%: 3 OR 10::36-65%;
          4 OR 11::66-85%; 5 OR 12::86-95%; 6 OR 13::96-99.5%:
          7 OR 14::99.5-100%
         VALUES READ IN FOR AMORT:
         AMORT(I,1)=EXPECTATION OF DIRECT MORTALITY
         FOLLOWING ARE CONDITIONAL EXPECTATIONS, GIVEN
         SURVIVAL OF DIRECT MORTALITY
         AMORT(I,2)=NO TOP KILL DAMAGE
         AMORT(I,3)=LEADER KILL
         AMORT(I,4)=1-10% TOP KILL
         AMORT(I,5)=1-25% TOP KILL
         AMORT(I,6)=1-50% TOP KILL
         AMORT(I,7)=1-99% TOP KILL

         VALUES OF AMORT AS RECALCULATED FOR OUTPUT

         AMORT(I,1)=EXPECTATION OF DIRECT MORTALTTY FROM DFTM
         AMORT(I,2)=EXPECTATION OF SECONDARY MORT., ALL CAUSES
         AMORT(I,3)=EXPECTATION OF TOP KILL, ALL DEGREES
         AMORT(I,4)=EXPECTATION OF GROWTH REDUCTION ONLY
         AMORT(I,5)=EXPECTATION OF LEADER KILL ONLY
         AMORT(I,6)=EXPECTATION OF 1-10% TOP KILL
         AMORT(I,7)=EXPECTATION OF 11-25% TOP KILL
         AMORT(I,8)=EXPECTATION OF 26-50% TOP KILL
         AMORT(I,9)=EXPECTATION OF 51-99% TOP KILL

         FOR BB ARRAY I=1 SIGNIFIES SECONDARY MORTALITY
         DUE TO BARK BEETLE
         I=2 SIGNIFIES SECONDARY MORTALITY DUE TO OTHER CAUSES
         BB(I,J=1 OR 7)=EXPECT. OF SECOND. MORT.,GIVEN
         NO TOP KILL DAMAGE
         BB(I,J=2 OR 8)=EXPECT. OF SECOND. MORT., GIVEN
         LEADER KILL
         BB(I,J=3 OR 9)=EXPECT. SECOND. MORT. GIVEN 0-10% TOP KILL
         BB(I,J=4 OR 10)=EXPECT. SECOND. MORT. GIVEN 11-25% TOP KILL
         BB(I,J=5 OR 11)=EXPECT. SECOND. MORT. GIVEN 26-50% TOP KILL
         BB(I,J=6 OR 12)=EXPECT. SECOND. MORT. GIVEN 51-99% TOP KILL
         BB ARRAY IS NOT OUTPUT BUT USED TO RECALCULATE THE
         AMORT OUTPUT MATRIX



     REWIND 13
     REWIND 14
     READ(13,7000)((AMORT(I,J),J=1,7),I=1,7)
     READ(13,7001) ((BB(I,J),J=1,6),I=1,2)
     READ(14,7000)((AMORT(I,J),J=1,7),I=8,14)
     READ(14,7001)((BB(I,J),J=7,12),I=1,2)
7000 FORMAT(1F7.4,6F6.3)
7001 FORMAT(1F7.4,5F6.3)

         COMPUTE THE TOTAL SECONDARY MORTALITY FROM
         ITS TWO COMPONENTS

     DO 770 J=1,12
770  BB(1,J)=BB(1,J)+BB(2,J)-(BB(1,J)*BB(2,J))

         SET UP POST-OUTBREAK EXPECTATIONS FROM INPUT DATA

     DO 100 I=1,14

         TRANSFORM CUMULATIVE TOP-KILL EXPECTATIONS TO
         EXPECTATIONS BY TOP-KILL CLASS

     DO 90 J=1,3
     JJ=8-J
     JJ1=JJ-1
90   AMORT(I,JJ)=AMORT(I,JJ)-AMORT(I,JJ1)

         REDUCE TOP-KILL EXPECTATIONS BY DIRECT MORTALITY

     DO 91 J=2,7
91   AMORT(I,J)=AMORT(I,J)*(1.-AMORT(I,1))
     IB=13
     IF(I.LT.8) IB=7
```

```
C
      DO 92 J=1,6
      JJ=10-J
      JJ2=JJ-2
      JB=IB-J
   92 AMORT(I,JJ)=(1.-BB(1,JB))*AMORT(I,JJ2)
      SUM=0.
C
C         CALCULATE PROPORTION OF TREES WHICH SURVIVE
C         AND SUFFER SOME GROWTH REDUCTION
C
      DO 93 J=5,9
   93 SUM=SUM+AMORT(I,J)
      AMORT(I,3)=SUM
      AMORT(I,2)=1.-AMORT(I,1)-AMORT(I,3)-AMORT(I,4)
  100 CONTINUE
C
C         REWIND INPUT LUNS
C
      DO 777 I=1,12
  777 REWIND I
C
C         SET PARAMETERS FOR CROWN DEFOLIATION EQUATION
C
      P1=-22.579678
      P2=-22.996253
      P3=-598181961.0
C
C         INITIALIZE OUTPUT FORMAT CONTROL INDICES
C         J: PAGE NUMBER
C         I:LINE NUMBER ON PAGE
C         INDEX: TOTAL LINES PRINTED
C         INDEXLIM: TOTAL NUMBER OF TREE CLASSES
C         IFLAG: FULL PAGE FLAG, 15 LINES
C         JMPFLAG:1 INDICATES LINE NEEDS NEW PAGE
C         BECAUSE OF NEW SPECIES OR FOLIAGE COMPLEMENT
C
      INDEXLTM=B(57)
      J=0
      INDEX=0
      JMPFLAG=0
C
C         NEW PAGE: RESET LINE COUNTERS
C
    1 I=0
      IFLAG=0
C
C         BEGIN NEW LINE: INCREMENT LINE COUNTERS
C
    2 I=I+1
      INDEX=INDEX+1
C
C         READ IN THE RESULTS OF THE FOUR YEAR OUTBREAK SIMU
C         RUN.  THE FOLLOWING CROSS-REFERENCE GUIDE IDENTIFI
C         LOCAL VARIABLES.
C         LOCAL      DESCRIPTION            FLEX                  P
C         -----      -----------            ----                  -
C                                           Z(6)  IN S0           A
C         IC(I,1)    HOST SPECIES           J, COUNTER FOR P      A
C         IC(I,2)    TREE CLASS NO.
C         IC(I,3)    LINE INDICATOR FOR AMORT TABLE
C
C         C(I,1)     NOMINAL % NEW FOL.     Z(2)  IN S0
C         C(I,2)     NOMINAL TOTAL FOL.     Z(3)  IN S0
C         C(I,3)     ACTUAL NEW FOL.        X(5)  IN S0
C         C(I,4)     ACTUAL OLD FOL.        X(6)  IN S0
C         C(I,5)     %CROWN DEFOLIATION
C
C         WT(I)      WEIGHTING FACTOR       Z(5)  IN S0
C
C                                           Z(4)  IN S0
C         A(I,1)     NO. OF TREES           X(7)  IN S0
C         A(I,2)     NO. OF VIABLE EGGS     X(5)+X(6)  IN S0
C         A(I,3)     TOTAL FOLIAGE
C         A(I,4)     ACTUAL % NEW FOL.      FROM Y(2)  IN S1
C         A(I,5)     % DEFOLIATION          Y(3)  IN S1
C         A(I,6)     EGGS LAID              G(2)  IN S0
C         A(I,7)     REDIST. EGGS           X(7)  IN S0
C         A(I,8)     NO. OF VIABLE EGGS     X(5)+X(6)  IN S0
C         A(I,9)     TOTAL FOLIAGE
C
```

```
C         A(I,13)  REDIST. EGGS        G(2) IN S0
C         A(I,14)  NO. OF VIABLE EGGS  X(7) IN S0
C         A(I,15)  TOTAL FOLIAGE       X(5)+X(6) IN S0
C         A(I,16)  ACTUAL % NEW FOL.
C         A(I,17)  % DEFOLIATION       FROM Y(2) IN S1
C         A(I,18)  EGGS LAID           Y(3) IN S1
C         A(I,19)  REDIST. EGGS        G(2) IN S0
C         A(I,20)  NO. OF VIABLE EGGS  X(7) IN S0
C         A(I,21)  TOTAL FOLIAGE       X(6)+X(5) IN S0
C         A(I,22)  ACTUAL % NEW FOL.
C         A(I,23)  % DEFOLIATION       FROM Y(2) IN S1
C         A(I,24)  EGGS LAID           Y(3) IN S1
C         A(I,25)  REDIST. EGGS        G(2) IN S0
C         A(I,26)  % OF TREE NOT DEFOLIATED
C
      READ(1,1001) IC(I,1),A(I,1),WT(I),C(I,1),C(I,2),C(I
     C  A(I,2),IC(I,2)
 1001 FORMAT (I2,7F11.5,I3)
      A(I,3)=C(I,3)+C(I,4)
      A(I,4)=100.*C(I,3)/A(I,3)
      READ(2,1002) C(I,4),A(I,6)
 1002 FORMAT (12X,2F12.6)
      A(I,5)=100.0-100.0*C(I,4)/C(I,2)
      READ(3,1003) A(I,7)
 1003 FORMAT(1F12.6)
      READ(4,1004) C(I,3),C(I,4),A(I,8)
 1004 FORMAT (46X,3F11.5,3X)
      A(I,9)=C(I,3)+C(I,4)
      A(I,10)=C(I,3)*100./A(I,9)
      READ(5,1002) C(I,4),A(I,12)
      A(I,11)=100.0-C(I,4)*100.0/C(I,2)
      READ(6,1003) A(I,13)
      READ(7,1004) C(I,3),C(I,4),A(I,14)
      A(I,15)=C(I,3)+C(I,4)
      A(I,16)=C(I,3)*100./A(I,15)
      READ(8,1002) C(I,4),A(I,18)
      A(I,17)=100.0-C(I,4)*100.0/C(I,2)
      READ(9,1003) A(I,19)
      READ (10,1004) C(I,3),C(I,4),A(I,20)
      A(I,21)=C(I,3)+C(I,4)
      A(I,22)=C(I,3)*100.0/A(I,21)
      READ (11,1002) C(I,4),A(I,24)
      A(I,23)=100.0-C(I,4)*100.0/C(I,2)
      READ (12,1003) A(I,25)
C
C         CALCULATE MAXIMUM % OF FOLIAGE WHICH SURVIVED I
C
      X1=FMAX(A(I,5),A(I,11))
      X2=FMAX(A(I,17),A(I,23))
      A(I,26)=100.-FMAX(X1,X2)
C
C         IF FIRST LINE, GO WRITE PAGE HEADER
C
      IF (I.EQ.1) GO TO 4
C
C         CHECK FOR NEW HOST SPECIES OR DIFFERENT NOMINAL
C         FOLIAGE COMPLEMENT.  IF DIFFERENT, SET FLAG AND
C         START NEW PAGE
C
      IF (IC(I-1,1).NE.IC(I,1)) JMPFLAG=1


      INC1=IFIX(100.*C(I-1,1)+0.5)
      INC2=IFIX(100.*C(I,1)+.5)
      IF (INC1.NE.INC2) JMPFLAG=1
      IF(JMPFLAG.EQ.1) GO TO 3
C
C         IF LAST LINE ON PAGE, SET IFLAG=1; WRITE LINE.
C
      IF(I.EQ.15) IFLAG=1
C
C        COMPUTE CROWN DEFOLIATION AND FIND ASSOCIATED LI
C        OF MORTALITY AND TOP-KILL TABLE (AMORT)
C
 5    CONTINUE
      IF(A(I,17).GT.95.) GO TO 15
      T=(P1/(P2+P3*EXP(P1*A(I,17)/100.)))*100.
      GO TO 16
 15   T=96.9689+((A(I,17)-95.)/5.)*3.0311
```

```
      IF (T.GT.35..AND.T.LE.65.) IC(I,3)=3
      IF (T.GT.65..AND.T.LE.85.) IC(I,3)=4
      IF (T.GT.85..AND.T.LE.95.) IC(I,3)=5
      IF (T.GT.95..AND.T.LE.99.5) IC(I,3)=6
      IF (T.GT.99.5) IC(I,3)=7
      IF(IC(I,1).EQ.2) IC(I,3)=IC(I,3)+7
      C(I,5)=T
C
C         WRITE LINE(I) FOR TABLE 1 AND 2
C           ON UPPER HALF OF PAGE
C
      WRITE(15,2002) IC(I,2),(A(I,JJ),JJ=1,13)
      ICK=IC(I,3)
      WRITE(16,3002) IC(I,2),A(I,1),WT(I),A(I,2),A(I,5),A
     CA(I,17),A(I,23),C(I,5),(AMORT(ICK,JJ),JJ=1,4)
C
C         CHECK FOR FULL PAGE AND EOD
C
      IF (IFLAG.EQ.1) GO TO 18
      IF (INDEX.LT.INDEXLIM) GO TO 2
C
C                       DOUBLE SPACE TO BOTTOM HALF OF PAGE
C
    3 CONTINUE
      IJ=16-I
      DO 12 JJ=1,IJ
      WRITE (15,2002)
      WRITE (16,3002)
   12 CONTINUE
C
C          FINISH PRESENT PAGE HALF
C
   18 WRITE (15,2003)
      WRITE (16,3003)
      IX=I-JMPFLAG
      IF (IFLAG.EQ.1) IX=15
      DO 10 II=1,IX
      WRITE (15,2002) IC(II,2),A(II,1),(A(II,JJ),JJ=14,25
      ICK=IC(II,3)
      WRITE(16,3004) IC(II,2),A(II,1),WT(II),A(II,2),
     C(AMORT(ICK,JJ),JJ=5,9),
     CA(II,25),A(II,26),A(II,26)
   10 CONTINUE
      DO 200 K1=1,4
      WRITE(18,10000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),
     C COMP,TIME,IPHASE(K1),DATE
      K3=K1*6-4
      K4=6*K1+1
      DO 210 K2=1,IX
      WRITE(18,10100) IC(K2,2),A(K2,1),(A(K2,JJ),JJ=K3,K4
  210 CONTINUE
      ENDFILE 18
  200 CONTINUE
      WRITE(22,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),CO
     C TIME,DATE
      WRITE(22,21000)
      DO 220 K1=1,IX
      ICK=IC(K1,3)
      WRITE(22,21100) IC(K1,2),A(K1,2),A(K1,5),A(K1,11),
     C A(K1,17),C(K1,5),AMORT(ICK,1)
  220 CONTINUE
      ENDFILE 22
      WRITE(23,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1)
     C ,COMP,TIME,DATE
      WRITE(23,22000)
      DO 230 K1=1,IX
      ICK=IC(K1,3)
      WRITE(23,22100) IC(K1,2),A(K1,2),C(K1,5),
     C  (AMORT(ICK,KJJ),KJJ=1,4)
  230 CONTINUE
      ENDFILE 23
      WRITE(24,20000) J,(ISPECIES(JJ),JJ=IS,IM),C(1,1),
     C  COMP,TIME,DATE
      WRITE(24,23000)
      DO 240 K1=1,IX
      ICK=IC(K1,3)
      WRITE(24,23100) IC(K1,2),A(K1,2),AMORT(ICK,2),
     C  (AMORT(ICK,JJ),JJ=5,9)
  240 CONTINUE
```

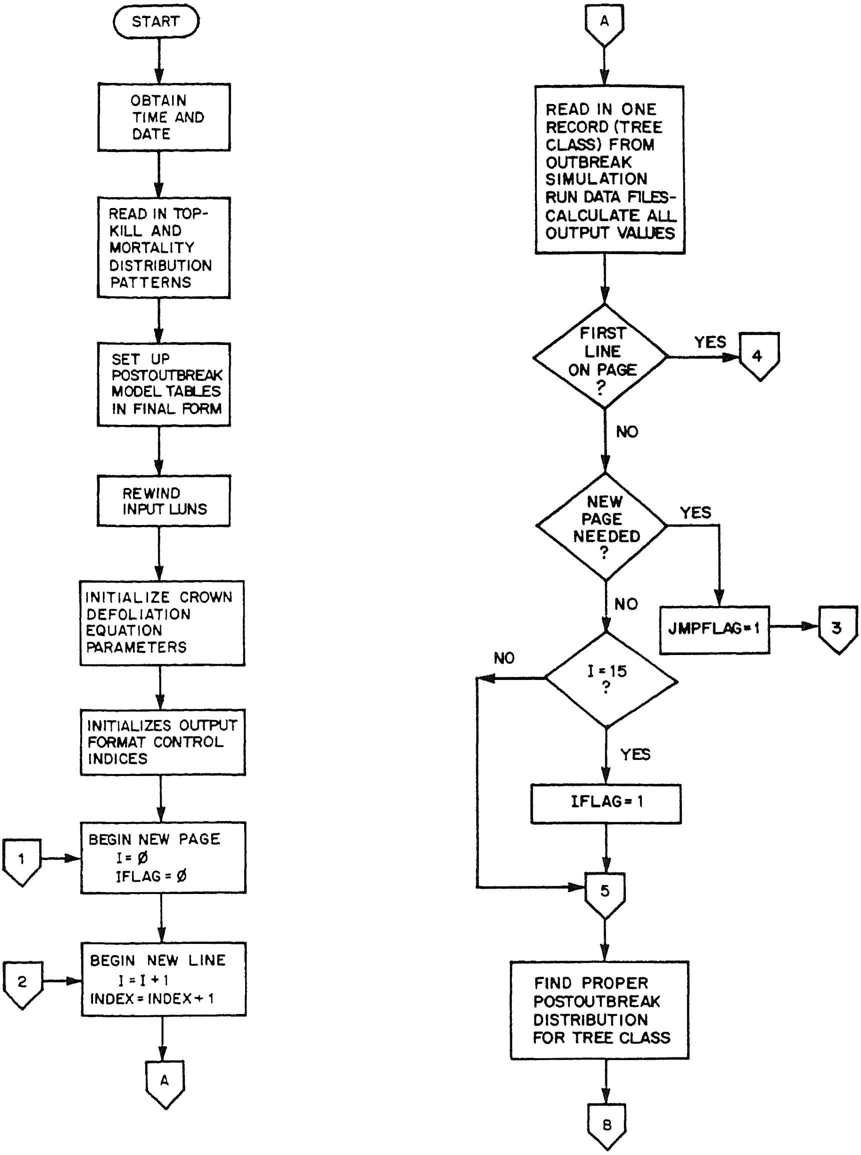
```
-C          IF NO MORE DATA, CHECK JMPFLAG FOR RETURN.
-C          IF MORE DATA, CHECK IFLAG FOR FULL PAGE.
-C
-      IF(INDEX.LT.INDEXLIM) GO TO 20
-      IF(JMPFLAG.NE.1) RETURN
-      GO TO 19
- 20   IF(IFLAG.EQ.1) GO TO 1
-C
-C                  *** LINE(I) IS FIRST LINE OF NEXT PAGE.
-C                      REPLACE A(1,J) WITH A(I,J), J=1,26
-C                      REPLACE IC(1,K) AND C(1,K) WITH
-C                      IC(I,K) AND C(I,K),K=1,2
-C
- 19   CONTINUE
-      DO 7 II=1,26
-      A(1,II)=A(I,II)
- 7    CONTINUE
-      IC(1,1)=IC(I,1)
-      IC(1,2)=IC(I,2)
-      C(1,1)=C(I,1)
-      C(1,2)=C(I,2)
-C
-C          WRITE OUT HEADER AND BEGIN NEW PAGE
-C
- 4    CONTINUE
-      J=J+1
-      I=1
-      JMPFLAG=0
-      IS=1
-      IF (IC(1,1).EQ.2) IS=4
-      IM = IS+2
-      COMP=100.-C(1,1)
-      WRITE (15,2001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(
-      WRITE (16,3001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(
-      GO TO 5
-C
-C ***** FORMAT STATEMENTS *****
-C
- 2001 FORMAT(≠1≠,9X,≠TABLE 1.≠,1I2,≠:    INPUT-OUTPUT VARIABL
-     C≠ VALUES OVER THE OUTBREAK CYCLE≠,32X,2(2X,A8),//
-     C,28X,≠FOR THE ≠,3A4,
-     CX,F6.3,≠ / ≠,F6.3,≠ TREE CLASSES≠///42X,≠PHASE I≠,49X,
-     C≠PHASE II≠/30X,≠INPUTS≠,21X,≠OUTPUTS≠,21X,≠INPUTS≠,21X
-     C≠OUTPUTS≠/≠ ≠,129(≠-≠)/≠0 TREE     NUMBER OF ≠,2(≠  VIA
-     C≠LE   TOTAL    PERCENT  DEFOLIA-  VIABLE    REDIS-  ≠),
-     C/≠  CLASS       STEMS     ≠,2(≠    EGGS   FOLIAGE     NEW≠,6
-     C≠TION      EGGS   TRIBUTED ≠)/≠     NO.≠,14X,2(10X,≠BIOMA
-     C≠FOLIAGE≠,13X,≠LAID       EGGS    ≠)/20X,2(≠   (NO.)   ≠
-     C≠(GRAMS)      (%)        (%)          (NO.)     (NO.)  ≠)/≠ ≠,
-     C129(≠-≠))
-C
-C
- 2002 FORMAT(≠0  ≠,I3,5X,F8.3,X,2(X,6(F7.3,2X),X))
- 2003 FORMAT(≠0≠,129(≠-≠)/42X,≠PHASE III≠,47X,≠PHASE IV≠/≠ ≠
-     C 129(≠-≠))
-C
-C
- 3001 FORMAT(≠1≠,9X,≠TABLE 2.≠,I2,≠:    OUTBREAK DEFOLIATION
-     C≠ AND THE EXPECTED MORTALITY AND GROWTH REDUCTION≠,
-     C14X,2(2X,A8),//,35X,≠FOR THE ≠,
-     C3A4,X,F6.3,≠ / ≠,F6.3,≠ TREE CLASSES≠//X,125(≠-≠)/
-     C≠  TREE   NUMBER  WEIGHT  INITIAL :       MODEL BRANCH:≠
-     C17X,≠PERCENT OF :  PROPORTION OF TREES RECEIVING:≠/
-     C≠  CLASS     OF     FACTOR   VIABLE :  PERCENT DEFOLIATI
-     C≠ BY PHASE≠,8X,≠TREE       :≠,45(≠-≠)/
-     C≠    NO.     TREES     PER       EGGS  :≠,34(≠-≠),≠    TOTAL
-     C≠DIRECT    SECONDARY     TOP   ONLY GROWTH≠/
-     C18X,≠TREE    PHASE I :    I≠,7X,≠II≠,7X,≠III≠,6X,≠IV
-     C≠DEFOLIATED : MORTALITY  MORTALITY      KILL   REDUCTIO
-     CX,125(≠-≠))
-C
- 3002 FORMAT (≠0   ≠,I3,3X,2(F6.1,2X),X,F7.3,3X,
-     CF6.3,2X,4(F7.3,2X),2X,4(F7.4,4X))
-C
-
- 3003 FORMAT(≠0≠,120(≠-≠)/≠  TREE    NUMBER  WEIGHT  INITIAL
-     C6X,≠PROPORTION OF TREES BY≠,7X,≠:  GROWTH IN SURVIVING
-     C≠DIAMETER GROWTH IN≠/
-     C≠  CLASS     OF     FACTOR   VIABLE : PERCENT REDUCTION
```

```
      C≠CROWN HEIGHT : TREES WITH NO TOP KILL : TREES WITH TOP
      C≠   NO.     TREES     PER       EGGS   : ≠,33(≠-≠),≠ :    ≠,
      C≠PERCENT OF NOMINAL    : ≠,19(≠-≠)/
      C18X,≠TREE    PHASE I :  0.0     5.0    17.5    37.5     70.0
      C≠DIAMETER   HEIGHT       : PERCENT OF NOMINAL≠/X,120(≠-≠))
 3004 FORMAT(≠0   ≠,I3,3X,F6.1,3X,F5.1,3X,F5.2,3X,4(F6.4,X),X,
      CF6.4,3X,2(F6.2,4X),10X,F6.2)

10000 FORMAT (≠ TABLE 1.≠,I2,≠:  INPUT-OUTPUT VARIABLE VALUES ≠
      C ≠OVER THE OUTBREAK≠/5X,≠CYCLE FOR THE ≠,3A4,F5.2,
      C ≠/≠,F5.2,≠ TREE CLASSES.≠/57X,A8/35X,≠PHASE ≠,A3,
      C 13X,A8/1X,13(≠-≠),≠[-------- INPUTS -------]≠,
      C ≠[------- OUTPUTS --------]≠/≠ TREE   NUMBER   INITIAL   TO
      C ≠   PERCENT   DEFOLIA VIABLE   REDIS-≠/≠ CLASS    OF       VIA
      C ≠BLE  FOLIAGE    NEW     -TION   EGGS   TRIBUTED ≠/≠  NO.
      C ≠    STEMS    EGGS   BIOMASS FOLIAGE≠,11X,≠LAID      EGGS≠/
      C 16X,≠(NO.)   (GRAMS)    (%)≠,6X,≠(%)      (NO.)      (NO.)≠/,
      C 1X,64(≠-≠))
10100 FORMAT (1X,I3,2X,F7.2,1X,6(1X,F7.3))
20000 FORMAT(≠ TABLE 2.≠,I2,≠:  OUTBREAK DEFOLIATION SUMMARY ≠,
      C≠AND THE ASSOCIATED≠/5X,≠MORTALITY PROBABILITIES FOR THE
      C,3A4,F5.2,≠/≠,F5.2/5X,≠TREE CLASSES.≠,22X,2(2X,A8)/)
21000 FORMAT(≠ ------ A: DEFOLIATION SUMMARY ≠,35(≠-≠)/≠ TREE ≠
      C≠ INITIAL≠,5X,≠BRANCH PERCENT       PERCENT OF  EXPECTATIO
      C/≠ CLASS   VIABLE   DEFOLIATION BY PHASE≠,7X,≠TREE≠,8X,≠OF≠
      C≠   NO.     EGGS   ≠,22(≠-≠),≠      TOTALLY       DIRECT≠/7X,
      C≠PHASE I      I        II        III    DEFOLIATED    MORTALITY≠,
      C/≠ ≠,64(≠-≠))
21100 FORMAT(2X,I3,1X,4(1X,F7.3),2X,F7.3,5X,F7.4)
22000 FORMAT(≠ ------ B: MORTALITY PROBABILITIES ≠,31(≠-≠)/,
      C≠ TREE   INITIAL  PERCENT≠,13X,≠EXPECTATION OF≠/≠ CLASS≠
      C,≠  VIABLE  OF TREE ≠,41(≠-≠)/≠  NO.      EGGS    DEFOL-≠,
      C≠    DIRECT    SECONDARY     TOP   NO TOP KILL≠/7X,≠PHASE I≠,
      C≠     IATED MORTALITY MORTALITY  KILL     DAMAGE≠/≠ ≠,64(≠-≠
22100 FORMAT(1X,I3,3X,2(F7.3,2X),4(F7.4,2X))
23000 FORMAT (≠ ------ C: TOP KILL PROBABILITIES ≠,31(≠-≠)/,
      C≠ TREE   INITIAL≠/≠ CLASS   VIABLE≠,14X,≠EXPECTATION OF TOP
      C≠ KILL≠/≠   NO.      EGGS   ≠,50(≠-≠)/7X,≠PHASE I      ANY       L
      C≠EADER  1-10%  11-25%  26-50%  51-90% ≠/≠ ≠,64(≠-≠))
23100 FORMAT(1X,I3,3X,F7.3,2X,6(F7.4,1X))
      END
F ON INPUT UNIT
```

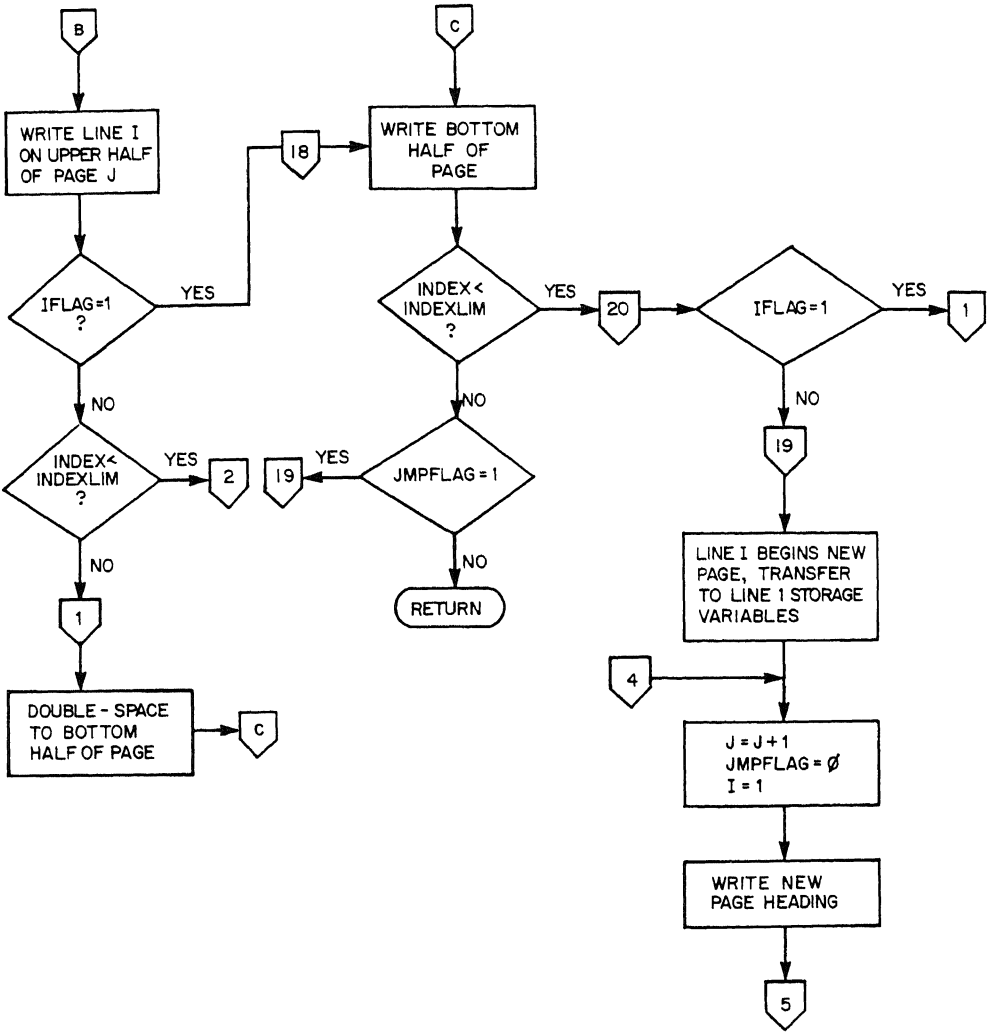
```
      SUBROUTINE TABLE32(B)
      DIMENSION B(1)
C
C         WRITE THE DESTRUCTION/CONSUMPTION RATIOS AND
C         INDIVIDUAL BIOMASS GROWTH RATES ON TABLE 3, LUN 17
C
      WRITE (17,1500) (B(J),J=7,12)
 1500 FORMAT(≠  ≠,24(≠-≠)/≠0 DESTRUCTION/CONSUMPTION≠/
     C≠ ≠,10X,≠RATIOS≠/≠  ≠,24(≠-≠)/≠0≠,8X,≠NEW FOLIAGE≠,
     C8X,≠I,II,III    DF,GF≠,5X,6(F6.3,X))
      WRITE (17,1550) (B(J),J=13,18)
 1550 FORMAT(≠0≠,8X,≠OLD FOLIAGE≠,8X,≠I,II,III    CF,GF≠,5X,
     C6(F6.3,X))
      WRITE (17,1600) B(22),B(22),B(22),B(23),B(24),B(24)
 1600 FORMAT(≠  ≠,24(≠-≠)/≠0≠,5X,≠INDIVIDUAL≠/≠    BIOMASS≠
     C≠ GROWTH RATE≠,5X,≠I,II,III    CF,GF≠,5X,6(F6.4,X))
      RETURN
      END
C
C
C
C
C
      SUBROUTINE S2(X,KP,F0404)
      DIMENSION IBOUT(8),IXOUT(8),XOUT(4)
      DIMENSION X(1)
      EQUIVALENCE (IBOUT(1),X1),(IBOUT(3),X2),(IBOUT(5),X3)
      EQUIVALENCE (IBOUT(7),X4),(IXOUT(1),XOUT(1)),(IXOUT(3),
      EQUIVALENCE (IXOUT(5),XOUT(3)),(IXOUT(7),XOUT(4))
C
C         AT KP=0, WRITE CURRENT STATE VARIABLES ON LUNS 21
C         AT ALL OTHER TIME STEPS WRITE UPDATED
C         VALUES ONLY ON 21 AND 25
C
      X1=X(1)+(F(1,1)-F(1,2))*0.10
      X2=X(2)+(F(2,2)+F(1,2))*0.10
      X3=X(3)+F(3,3)*0.10
      X4=X(4)+F0404*0.10
      IF(KP.EQ.0) WRITE(21,1000) X(1),X(2),X(3),X(4)
      WRITE (21,1000) X1,X2,X3,X4
 1000 FORMAT (4(2X,F14.7))
      IF (KP.EQ.9) WRITE (21,1000)
      DO 1 I=1,4
 1    XOUT(I)=X(I)
      IF(KP.EQ.0) BUFFER OUT(25,1) (IXOUT(1),IXOUT(8))
      CALL UNITST(25,IB25)
      IF(KP.NE.9) BUFFER OUT(25,1) (IBOUT(1),IBOUT(8))
      RETURN
      END
EOF ON INPUT UNIT
```

routine TABLE12 flowchart


START
OBTAIN TIME AND DATE
READ IN TOP-KILL AND MORTALITY DISTRIBUTION PATTERNS
SET UP POSTOUTBREAK MODEL TABLES IN FINAL FORM
REWIND INPUT LUNS
INITIALIZE CROWN DEFOLIATION EQUATION PARAMETERS
INITIALIZES OUTPUT FORMAT CONTROL INDICES
1
BEGIN NEW PAGE
I = 0
IFLAG = 0
2
BEGIN NEW LINE
I = I + 1
INDEX = INDEX + 1
A
A
READ IN ONE RECORD (TREE CLASS) FROM OUTBREAK SIMULATION RUN DATA FILES-CALCULATE ALL OUTPUT VALUES
FIRST LINE ON PAGE ?
YES
4
NO
NEW PAGE NEEDED ?
YES
JMPFLAG = 1
3
NO
I = 15 ?
NO
YES
IFLAG = 1
5
FIND PROPER POSTOUTBREAK DISTRIBUTION FOR TREE CLASS
B

Note: The numbers inside symbol ⬠ are statement labels in the code for subroutine TABLE12.

Subroutine TABLE12 flowchart (continued)


B
WRITE LINE I ON UPPER HALF OF PAGE J
IFLAG=1 ?
YES
18
NO
INDEX< INDEXLIM ?
YES
2
NO
1
DOUBLE - SPACE TO BOTTOM HALF OF PAGE
C
C
WRITE BOTTOM HALF OF PAGE
INDEX< INDEXLIM ?
YES
20
NO
JMPFLAG = 1
YES
19
NO
RETURN
IFLAG=1
YES
1
NO
19
LINE I BEGINS NEW PAGE, TRANSFER TO LINE 1 STORAGE VARIABLES
4
J = J + 1
JMPFLAG = 0
I = 1
WRITE NEW PAGE HEADING
5

APPENDIX B VERSION 2.2 VERIFICATION OUTPUT

Page

Model parameterization 77

Simulation output 77

```
INITIAL TIME         0      DATA DUMP INTERVAL     1                  CONTROL INPUT LUN  54     CONTROL OUTPUT LUN  61
TERMINATION         10      LP PRINT INTERVAL      1                  LINE PRINTER LUN    1     FUNCTION INPUT LUN  52
RESOLUTICN RATIO     1                                                DATA DUMP LUN       2

                 ( 1)         ( 2)         ( 3)         ( 4)

INITIAL X     5.0400E 01   9.3600E 01   7.5000E 01      0E 00

R CONSTANTS       0E 00        0E 00        0E 00        0E 00   1.0000E-03   1.0000E-03       0E 00        0E 00        0E 00        0E 00
              1.0000E-03   1.0000E-03   1.0000E 00   8.0000E-01   5.0000E-01   1.0000E-01

B CONSTANTS   2.0000E-02   2.0000E-02   2.0000E-02   2.0000E-02   2.0000E-02   2.0000E-02   5.4000E 00   6.2500E 00   6.2500E 00   2.7100E 00
              2.2700E 00   2.0000E 00   5.4000E 00   6.2500E 00   6.2500E 00   3.6900E 00   3.2900E 00   3.0000E 00   1.1900E 00   8.1000E-02
              1.0000E-01   1.1470E-01   8.8600E-02   6.2500E-02   1.9700E-01   5.2063E 01   2.0000E-02   1.0000E-02   2.0000E 00   5.0000E-01
              3.5000E 01   1.4400E 02       0E 00   6.2000E-01   2.0000E 02       0E 00   6.0000E-01

FLOW FUNCTIONS 0 * = DEFINED

         1  2  3  4
F( 1,J)  *  *  0  0
F( 2,J)  0  *  0  0
F( 3,J)  0  0  *  0
F( 4,J)  0  0  0  *

INDICES  OF DEFINED G FUNCTIONS
  1   2   3   4   5   6   7   8    9  10   11   12   13   14   15   16   17   18   19

INDICES OF DEFINED H FUNCTIONS

YCOMP SUBROUTINE IS DEFINED
ZCOMP SUBROUTINE IS UNCEFINED


PAGE    1   07/28/77   11:01 PM   SIMULATION ON THE REVISED MODEL VERS. 2.2
            07282301              MODEL SEQUENCE NO. 1000 0000 0000

    TIME       Y( 1)         Y( 2)         Y( 3)         Y( 4)         G( 1)         G( 2)         G( 3)         G( 4)         G( 5)         G( 6)
               G( 7)         G( 8)         G( 9)         G(10)         G(11)         G(12)         G(13)         G(14)         G(15)         G(16)
               G(17)         G(18)         G(19)

     0     50.400000     93.600000     75.000000             0            -0            -0            -0            -0            -0            -0
                  -0            -0            -0            -0            -0            -0            -0            -0            -0            -0
                  -0            -0            -0

     1     50.400000     93.600000     75.000000       .197000             0             0             0             0             0             0
                   0             0             0             0             0             0       .197000             0             0             0
                   0             0             0

     2     47.482112     93.600000     61.280461       .620300             0             0             0      2.917888             0       .980000
                   0     -0.182927             0             0    -13.719539       .114700       .423300             0     10.000000      2.917888
                   0             0             0

     3     38.793482     93.600000     50.070598      1.953160             0             0             0      8.688631             0       .980000
             .200000     -0.182927             0             0    -11.209863       .114700      1.332859             0     10.000000      8.688631
                   0             0             0

     4     16.439862     93.600000     40.911324      6.149978             0             0             0     22.353620             0       .980000
             .500000     -0.182927             0             0     -9.159274       .114700      4.196818             0     10.000000     22.353620
                   0             0             0

     5             0     90.716618     30.084777     14.916209             0             0             0     16.439862      2.883382       .980000
             .900000     -0.264634      1.000000             0    -10.826547       .088600      8.766231             0      9.000000     18.433652
            1.000000      2.883382             0

     6             0     62.148494     12.047233     27.867146             0             0             0             0     28.568125       .978041
            1.000000     -0.199114     11.000000     -0.400443    -18.037544       .062500     12.950938             0             0             0
           10.000000     28.568125             0

     7             0     42.659848      9.648457     52.062684             0             0             0             0
```

APPENDIX C VERSION 3.1 VERIFICATION INPUT AND OUTPUT

Page

Inputs:

LUN1 79

LUN13 79

LUN14 79

Outputs:

Table 1 80

Table 2 82

Table 3 84

Table 4 85

```
001 - 2    1.0    1.0    35.0    144.0    50.40    93.60    0.1
002 - 2    1.0    1.0    35.0    144.0    50.40    93.60    0.5
003 - 2    1.0    1.0    35.0    144.0    50.40    93.60    1.0
004 - 2    1.0    1.0    35.0    144.0    50.40    93.60    2.0
~~005 - 2    1.0    1.0    35.0    144.0    50.40    93.60    3.0~~
006 - 2    1.0    1.0    35.0    144.0    50.40    93.60    3.5
007 - 2    1.0    1.0    35.0    144.0    50.40    93.60    4.0
~~008 - 2    1.0    1.0    35.0    144.0    50.40    93.60    4.5~~
009 - 2    1.0    1.0    35.0    144.0    50.40    93.60    5.0
010 - 2    1.0    1.0    35.0    144.0    50.40    93.60    6.0    1
011 - 2    1.0    1.0    35.0    144.0    50.40    93.60    8.0    1
012 - 2    1.0    1.0    35.0    144.0    50.40    93.60   10.0    1
~~013 - 1    1.0    1.0    30.0    100.0    30.0     70.0     0.1    1~~
014 - 1    1.0    1.0    30.0    100.0    30.0     70.0     0.5    1
015 - 1    1.0    1.0    30.0    100.0    30.0     70.0     1.0    1
~~016 - 1    1.0    1.0    30.0    100.0    30.0     70.0     2.0    1~~
017 - 1    1.0    1.0    30.0    100.0    30.0     70.0     3.0    1
018 - 1    1.0    1.0    30.0    100.0    30.0     70.0     3.5    1
019 - 1    1.0    1.0    30.0    100.0    30.0     70.0     4.0    1
020 - 1    1.0    1.0    30.0    100.0    30.0     70.0     4.5    2
~~021 - 1    1.0    1.0    30.0    100.0    30.0     70.0     5.0    2~~
022 - 1    1.0    1.0    30.0    100.0    30.0     70.0     6.0    2
023 - 1    1.0    1.0    30.0    100.0    30.0     70.0     8.0    2
~~024 - 1    1.0    1.0    30.0    100.0    30.0     70.0    10.0    2~~
F ON INPUT UNIT
```

LUN13

```
001 -0.000   0.879 0.073 0.048 0.048 0.048 0.048
002 -0.000   0.762 0.143 0.072 0.072 0.072 0.095
003 -0.009   0.555 0.191 0.222 0.222 0.254 0.254
004 -0.028   0.457 0.257 0.171 0.171 0.286 0.286
005 -0.173   0.475 0.175 0.075 0.075 0.200 0.350
006 -0.477   0.462 0.308 0.076 0.076 0.076 0.230
007 -0.923   0.462 0.308 0.076 0.076 0.076 0.230
008 -0.068   0.000 0.034 0.333 0.250 0.667
009 -0.076   0.049 0.000 0.143 0.000 0.667
F ON INPUT UNIT
```

LUN14

```
001 -0.000   0.940 0.035 0.013 0.017 0.021 0.025
002 -0.000   0.867 0.090 0.031 0.039 0.041 0.042
003 -0.009   0.712 0.138 0.095 0.128 0.141 0.150
004 -0.028   0.569 0.183 0.111 0.157 0.209 0.248
005 -0.173   0.493 0.240 0.075 0.103 0.123 0.267
006 -0.477   0.460 0.189 0.081 0.135 0.135 0.351
007 -0.923   0.460 0.189 0.081 0.135 0.135 0.351
008 -0.014   0.005 0.022 0.333[1] 0.053 0.472
009 -0.029   0.021 0.032 0.000 0.000 0.143
F ON INPUT UNIT
```

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[1] The value 0.333 for this parameter was used for validation simulation e updated value 0.030 should be substituted for any further use of this ameter.

TABLE 1. 1: INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE

FOR THE GRAND FIR 35.000 / 65.000 TREE CLASSES

		PHASE I						PHASE II					
		INPUTS			OUTPUTS			INPUTS			OUTPUTS		
TREE CLASS NO.	NUMBER OF STEMS	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)
1	1.000	.100	144.000	35.000	.083	1.488	1.488	.744	143.979	34.991	.626	8.081	8.081
2	1.000	.500	144.000	35.000	.414	7.439	7.439	3.719	143.896	34.953	3.128	40.406	40.406
3	1.000	1.000	144.000	35.000	.828	14.878	14.878	7.439	143.791	34.906	6.256	80.811	80.811
4	1.000	2.000	144.000	35.000	1.655	29.755	29.755	14.878	143.583	34.811	12.513	161.623	161.623
5	1.000	3.000	144.000	35.000	2.483	44.633	44.633	22.316	143.374	34.716	18.769	242.434	242.434
6	1.000	3.500	144.000	35.000	2.897	52.072	52.072	26.036	143.270	34.669	21.898	282.840	282.840
7	1.000	4.000	144.000	35.000	3.310	59.511	59.511	29.755	143.166	34.621	25.026	323.245	323.245
8	1.000	4.500	144.000	35.000	3.724	66.349	66.949	33.475	143.062	34.574	28.154	363.651	363.651
9	1.000	5.000	144.000	35.000	4.138	74.388	74.388	37.194	142.957	34.526	31.282	404.057	404.057
10	1.000	6.000	144.000	35.000	4.966	89.266	89.266	44.633	142.749	34.430	38.878	465.473	465.473
11	1.000	8.000	144.000	35.000	6.621	119.021	119.021	59.511	142.332	34.238	57.540	543.052	543.052
12	1.000	10.000	144.000	35.000	8.276	148.777	148.777	74.388	141.914	34.045	68.281	510.566	510.566

		PHASE III						PHASE IV					
1	1.000	3.232	143.842	34.929	1.922	3.525	3.525	.529	143.516	34.781	.467	.095	.095
2	1.000	16.162	143.212	34.642	9.610	17.626	17.626	2.644	141.578	33.888	2.337	.474	.474
3	1.000	32.325	142.423	34.280	19.219	35.253	35.253	5.288	139.157	32.738	4.674	.948	.948
4	1.000	64.649	140.847	33.545	40.324	62.045	62.045	9.307	126.172	31.892	14.688	1.668	1.668
5	1.000	96.974	139.270	32.792	53.323	36.926	36.926	5.539	104.178	35.480	29.028	.993	.993
6	1.000	113.136	138.482	32.410	46.510	14.843	14.843	2.226	115.705	33.429	20.201	.399	.399
7	1.000	129.298	137.693	32.023	45.504	8.359	8.359	1.254	117.407	33.161	18.778	.225	.225
8	1.000	145.460	136.905	31.632	40.543	2.282	2.282	.342	125.802	31.942	12.722	.061	.061
9	1.000	161.623	136.117	31.236	40.860	1.248	1.248	.187	125.264	32.015	13.057	.034	.034
10	1.000	186.489	128.619	31.568	43.673	.348	.348	.052	120.505	32.691	16.329	.009	.009
11	1.000	217.221	97.042	36.994	63.828	.098	.098	.015	86.404	39.715	40.001	.003	.003
				[illegible]	[illegible]	.046	.046	.007	73.227	44.182	49.150	.001	.001

FOR THE DOUGLAS-FIR 30.000 / 70.000 TREE CLASSES

		PHASE I						PHASE II					
		INPUTS			OUTPUTS			INPUTS			OUTPUTS		
TREE CLASS NO.	NUMBER OF STEPS	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)	VIABLE EGGS (NO.)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIATION (%)	VIABLE EGGS LAID (NO.)	REDISTRIBUTED EGGS (NO.)
13	1.000	.100	100.000	30.000	.119	1.488	1.488	.744	99.982	29.987	.898	8.081	8.081
14	1.000	.500	100.000	30.000	.596	7.439	7.439	3.719	99.911	29.937	4.490	40.406	40.406
15	1.000	1.000	100.000	30.000	1.192	14.878	14.878	7.439	99.821	29.875	8.980	80.811	80.811
16	1.000	2.000	100.000	30.000	2.383	29.755	29.755	14.878	99.642	29.749	17.959	161.623	161.623
17	1.000	3.000	100.000	30.000	3.575	44.633	44.633	22.316	99.464	29.623	26.938	242.434	242.434
18	1.000	3.500	100.000	30.000	4.171	52.072	52.072	26.036	99.374	29.559	32.289	274.354	274.354
19	1.000	4.000	100.000	30.000	4.767	59.511	59.511	29.755	99.285	29.496	39.247	287.688	287.688
20	1.000	4.500	100.000	30.000	5.363	66.949	66.949	33.475	99.196	29.432	45.601	312.740	312.740
21	1.000	5.000	100.000	30.000	5.959	74.388	74.388	37.194	99.106	29.369	52.094	335.367	335.367
22	1.000	6.000	100.000	30.000	7.150	89.266	89.266	44.633	98.927	29.241	65.053	378.197	378.197
23	1.000	8.000	100.000	30.000	9.534	119.021	119.021	59.511	98.570	28.984	90.280	459.008	459.008
24	1.000	10.000	100.000	30.000	11.917	148.777	148.777	74.388	98.212	28.726	98.207	445.109	445.109

		PHASE III						PHASE IV					
13	1.000	3.232	99.865	29.986	2.745	3.525	3.525	.529	99.588	29.711	.600	.095	.095
14	1.000	16.162	99.327	29.525	13.723	17.626	17.626	2.644	97.942	28.529	3.002	.474	.474
15	1.000	32.325	98.653	29.044	27.446	35.253	35.253	5.288	95.883	26.994	6.005	.948	.948
16	1.000	64.649	97.306	28.062	65.568	49.354	49.354	7.403	54.596	36.934	48.047	1.327	1.327
17	1.000	96.974	95.959	27.052	73.009	40.592	40.592	6.089	46.039	41.375	56.135	1.091	1.091
18	1.000	109.742	92.868	27.089	80.135	40.707	40.707	6.106	37.845	47.509	64.336	1.094	1.094
19	1.000	115.075	84.866	28.413	86.642	37.817	37.817	5.673	30.362	56.004	71.664	1.016	1.016
20	1.000	125.096	77.559	29.861	94.962	36.412	36.412	5.462	20.794	75.771	81.156	.979	.979
21	1.000	134.147	70.092	31.653	100.000	16.511	16.511	2.477	11.400	100.000	89.484	.444	.444
22	1.000	151.279	55.189	36.678	80.590	8.485	8.485	1.273	37.321	47.993	63.133	.228	.228
23	1.000	183.603	26.178	62.869	91.553	.037	.037	.006	24.714	65.822	75.288	.001	.001

TABLE 2. 1: OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION

FOR THE GRAND FIR 35.000 / 65.000 TREE CLASSES

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	MODEL BRANCH: PERCENT DEFOLIATION BY PHASE I	II	III	IV	PERCENT OF TREE TOTALLY DEFOLIATED	PROPORTION OF TREES RECEIVING: DIRECT MORTALITY	SECONDARY MORTALITY	TOP KILL	ONLY GROWTH REDUCTION
1	1.0	1.0	.100	.083	.626	1.922	.467	.000	0	.0454	.0547	.9000
2	1.0	1.0	.500	.414	3.128	9.610	2.337	.000	0	.0454	.0547	.9000
3	1.0	1.0	1.000	.828	6.256	19.219	4.674	.000	0	.0454	.0547	.9000
4	1.0	1.0	2.000	1.655	12.513	40.324	14.688	.034	0	.0454	.0547	.9000
5	1.0	1.0	3.000	2.483	18.769	53.323	29.028	.635	0	.0454	.0547	.9000
6	1.0	1.0	3.500	2.897	21.898	46.510	20.201	.137	0	.0454	.0547	.9000
7	1.0	1.0	4.000	3.310	25.026	45.504	18.778	.109	0	.0454	.0547	.9000
8	1.0	1.0	4.500	3.724	28.154	40.543	12.722	.036	0	.0454	.0547	.9000
9	1.0	1.0	5.000	4.138	31.282	40.860	13.057	.038	0	.0454	.0547	.9000
10	1.0	1.0	6.000	4.966	38.878	43.673	16.329	.072	0	.0454	.0547	.9000
11	1.0	1.0	8.000	6.621	57.540	63.828	40.001	6.407	0	.0454	.0547	.9000
12	1.0	1.0	10.000	8.276	68.281	71.615	49.150	28.310	0	.0452	.1247	.8301

TREE CLASS NO.	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	PROPORTION OF TREES BY PERCENT REDUCTION IN CROWN HEIGHT 0.0	5.0	17.5	37.5	70.0	GROWTH IN SURVIVING TREES WITH NO TOP KILL PERCENT OF NOMINAL DIAMETER	HEIGHT	DIAMETER GROWTH IN TREES WITH TOP KILL PERCENT OF NOMINAL
1	1.0	1.0	.10	.0341	.0123	.0027	.0038	.0018	98.08	98.08	98.08
2	1.0	1.0	.50	.0341	.0123	.0027	.0038	.0018	90.39	90.39	90.39
3	1.0	1.0	1.00	.0341	.0123	.0027	.0038	.0018	80.78	80.78	80.78
4	1.0	1.0	2.00	.0341	.0123	.0027	.0038	.0018	59.68	59.68	59.68
5	1.0	1.0	3.00	.0341	.0123	.0027	.0038	.0018	46.68	46.68	46.68
6	1.0	1.0	3.50	.0341	.0123	.0027	.0038	.0018	53.49	53.49	53.49
7	1.0	1.0	4.00	.0341	.0123	.0027	.0038	.0018	54.50	54.50	54.50
8	1.0	1.0	4.50	.0341	.0123	.0027	.0038	.0018	59.46	59.46	59.46
9	1.0	1.0	5.00	.0341	.0123	.0027	.0038	.0018	59.14	59.14	59.14
10	1.0	1.0	6.00	.0341	.0123	.0027	.0038	.0018	56.33	56.33	56.33
11	1.0	1.0	8.00	.0341	.0123	.0027	.0038	.0018	36.17	36.17	36.17
12	1.0	1.0	10.00	.0877	.0293	.0053	.0019	.0005	28.38	28.38	28.38

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TREE   NUMBER  WEIGHT  INITIAL :       MODEL BRANCH:                        PERCENT OF :  PROPORTION OF TREES RECEIVING:
CLASS    OF    FACTOR   VIABLE : PERCENT DEFOLIATION BY PHASE                  TREE     :-----------------------------------------------
 NO.   TREES    PER      EGGS  :-------------------------------------------   TOTALLY   :  DIRECT     SECONDARY      TOP    ONLY GROWTH
                TREE   PHASE I :   I          II         III         IV     DEFOLIATED  : MORTALITY   MORTALITY      KILL    REDUCTION
--------------------------------------------------------------------------------------------------------------------------------------

  13      1.0     1.0     .100     .119       .898      2.745       .600       .000           0        .1272        .1158      .7570
  14      1.0     1.0     .500     .596      4.490     13.723      3.002       .000           0        .1272        .1158      .7570
  15      1.0     1.0    1.000    1.192      8.980     27.446      6.005       .002           0        .1272        .1158      .7570
  16      1.0     1.0    2.000    2.383     17.959     65.568     48.047      9.203           0        .1272        .1158      .7570
  17      1.0     1.0    3.000    3.575     26.938     73.009     56.135     35.045       .0090        .1010        .4163      .4736
  18      1.0     1.0    3.500    4.171     32.289     80.135     64.336     72.169       .0280        .1075        .4820      .3825
  19      1.0     1.0    4.000    4.767     39.247     86.642     71.664     90.667       .1730        .1999        .2888      .3383
  20      1.0     1.0    4.500    5.363     45.601     94.962     81.156     96.959       .4770        .1144        .2005      .2081
  21      1.0     1.0    5.000    5.959     52.094    100.000     89.484    100.000       .9230        .0168        .0295      .0306
  22      1.0     1.0    6.000    7.150     65.053     80.590     63.133     74.087       .0280        .1075        .4820      .3825
  23      1.0     1.0    8.000    9.534     90.280     91.553     75.288     95.573       .4770        .1144        .2005      .2081
  24      1.0     1.0   10.000   11.917     98.207    100.000     86.800    100.000       .9230        .0168        .0295      .0306



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TREE   NUMBER  WEIGHT  INITIAL :        PROPORTION OF TREES BY         :  GROWTH IN SURVIVING   : DIAMETER GROWTH IN
CLASS    OF    FACTOR   VIABLE : PERCENT REDUCTION IN CROWN HEIGHT     : TREES WITH NO TOP KILL : TREES WITH TOP KILL
 NO.   TREES    PER      EGGS  :--------------------------------------- :   PERCENT OF NOMINAL   :-------------------
                TREE   PHASE I :  0.0     5.0    17.5    37.5    70.0  : DIAMETER      HEIGHT   : PERCENT OF NOMINAL
-----------------------------------------------------------------------------------------------------------------------

  13      1.0     1.0     .10    .0694   .0464     0       0       0     97.26       97.26             97.26
  14      1.0     1.0     .50    .0694   .0464     0       0       0     86.28       86.28             86.28
  15      1.0     1.0    1.00    .0694   .0464     0       0       0     72.55       72.55             72.55
  16      1.0     1.0    2.00    .0694   .0464     0       0       0     34.43       34.43             34.43
  17      1.0     1.0    3.00    .1800   .2125     0     .0238     0     26.99       26.99             26.99
  18      1.0     1.0    3.50    .2376   .1606     0     .0838     0     19.86       19.86             19.86
  19      1.0     1.0    4.00    .1376   .0599     0     .0775   .0138   13.36       13.36             13.36
  20      1.0     1.0    4.50    .1532   .0384     0       0     .0089    5.04        5.04              5.04
  21      1.0     1.0    5.00    .0226   .0057     0       0     .0013      0           0                 0
  22      1.0     1.0    6.00    .2376   .1606     0     .0838     0     19.41       19.41             19.41
  23      1.0     1.0    8.00    .1532   .0384     0       0     .0089    8.45        8.45              8.45
  24      1.0     1.0   10.00    .0226   .0057     0       0     .0013      0           0                 0
```

TABLE 3: PARAMETERS FOR AN OUTBREAK: MORTALITY, FOLIAGE DESTRUCTION, AND OTHER. 23:01:52 08/18/77

HOST TREE, STAND, PHASE, OR INSTAR SPECIFIC.

DESCRIPTION	PHASE	SPECIES	INSTAR						PUPAE MORTALITY	OVERWINTER MORTALITY	EGG MASS SIZE
			1	2	3	4	5	6			
DAILY MORTALITY RATE											
BACKGROUND	I,II,III,IV	DF,GF	.020	.020	.020	.020	.020	.020			
DISEASE	I	DF,GF	0	0	0	0	0	0			
	II	DF,GF	0	0	0	0	.001	.001			
	III	DF,GF	.002	.003	.006	.013	.035	.028			
	IV	DF,GF	.025	.028	.031	.034	.035	.035			
PARASITE/PREDATOR	I	DF,GF	0	0	0	0	0	0			
	II	DF,GF	0	0	0	0	.001	.001			
	III	DF,GF	.001	.002	.003	.010	.016	.042			
	IV	DF,GF	.005	.006	.007	.021	.033	.056			
STRESS	I,II,III,IV	DF	1.000	.750	.100	0	0	0			
	I,II,III,IV	GF	1.000	.800	.500	.100	0	0			
OCCASION MORTALITY RATE											
PUPAE	I	DF,GF							.500		
	II	DF,GF							.620		
	III	DF,GF							.750		
	IV	DF,GF							.800		
OVERWINTER	I - II	DF,GF								.500	
	II - III	DF,GF								.600	
	III - IV	DF,GF								.850	
	IV-	DF,GF								.900	
NOMINAL EGG MASS SIZE	I	DF,GF									200.0
	II	DF,GF									200.0
	III	DF,GF									150.0
	IV	DF,GF									150.0
DESTRUCTION/CONSUMPTION RATIOS											
NEW FOLIAGE	I,II,III	DF,GF	5.400	6.250	6.250	2.710	2.270	2.000			
OLD FOLIAGE	I,II,III	DF,GF	5.400	6.250	6.250	3.690	3.290	3.000			
INDIVIDUAL BIOMASS GROWTH RATE	I,II,III	DF,GF	.1147	.1147	.1147	.0886	.0625	.0625			

PHASE SPECIFIC MEAN EGG DENSITIES: I= 59.015 II=268.836 III= 19.538 IV= .525

REDISTRIBUTION COEFFICIENT FOR THE OUTBREAK: 0

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48  DETAIL RUN INFORMATION, PAGE  1

         FOURTH INSTAR LARVAE                                THIRD INSTAR LARVAE                                 SIXTH INSTAR LARVAE

         FOR GRAND FIR   35.00% NEW FOLIAGE                  FOR GRAND FIR   35.00% NEW FOLIAGE                  FOR GRAND FIR   35.00% NEW FOLIAGE

LASS             I          II         III          IV              I          II         III          IV              I          II         III          IV

  1.          .055        .406       1.487        .103           .067        .497       1.992        .185           .018        .133        .235        .010
  2.          .273       2.029       7.436        .514           .334       2.483       9.960        .924           .091        .664       1.174        .049
  3.          .545       4.058      14.871       1.027           .668       4.966      19.919       1.848           .182       1.328       2.347        .098
  4.         1.091       8.116      29.742       1.808          1.335       9.932      39.838       3.252           .364       2.655       4.695        .173
  5.         1.636      12.173      44.614       1.076          2.003      14.899      59.757       1.935           .546       3.983       3.368        .103
  6.         1.909      14.202      26.025        .432          2.337      17.382      69.717        .778           .637       4.647       1.432        .041
  7.         2.182      16.231      14.871        .244          2.670      19.865      79.677        .438           .728       5.311        .818        .023
  8.         2.455      18.260       4.183        .066          3.004      22.348      89.636        .120           .819       5.974        .230        .006
  9.         2.727      20.289       2.324        .036          3.338      24.831      99.596        .065           .910       6.638        .128        .003
 10.         3.273      24.347        .669        .010          4.006      29.797     114.734        .018          1.093       7.966        .037        .001
 11.         4.364      32.462        .195        .003          5.341      39.730     133.857        .005          1.457      10.621        .011        .000
 12.         5.455      40.578        .092        .001          6.676      49.662     125.849        .002          1.821      10.754        .005        .000

         FOURTH INSTAR LARVAE                                THIRD INSTAR LARVAE                                 SIXTH INSTAR LARVAE

         FOR DOUGLAS FIR 30.00% NEW FOLIAGE                  FOR DOUGLAS FIR 30.00% NEW FOLIAGE                  FOR DOUGLAS FIR 30.00% NEW FOLIAGE

LASS             I          II         III          IV              I          II         III          IV              I          II         III          IV

 13.          .055        .406       1.487        .103           .067        .497       1.992        .185           .018        .133        .235        .010
 14.          .273       2.029       7.436        .514           .334       2.483       9.960        .924           .091        .664       1.174        .049
 15.          .545       4.058      14.871       1.027           .668       4.966      19.919       1.845           .182       1.328       2.347        .098
 16.         1.091       8.116      29.742       1.438          1.335       9.932      39.838       2.587           .364       2.655       4.695        .138
 17.         1.636      12.173      26.344       1.183          2.033      14.899      59.757       2.127           .546       3.983       4.158        .113
 18.         1.909      14.202      26.831       1.186          2.337      17.382      67.626       2.133           .637       4.647       4.235        .113
 19.         2.182      16.231      25.322       1.102          2.670      19.865      70.912       1.982           .728       5.311       3.997        .105
 20.         2.455      18.260      24.774       1.061          3.004      22.348      77.097       1.908           .819       5.974       3.911        .101
 21.         2.727      20.289      23.910        .481          3.338      24.831      82.665        .865           .910       6.638       3.774        .046
 22.         3.273      24.347       6.067        .247          4.036      29.797      23.305        .445          1.093       7.966        .958        .024
 23.         4.364      32.462        .029        .001          5.341      39.730        .110        .002          1.457      10.621        .005        .000
 24.         5.455      32.868        .028           0          6.676      49.662        .107           0          1.821      10.754        .004           0


         FALL PUPAE

         FOR GRAND FIR   35.00% NEW FOLIAGE

LASS             I          II         III          IV

  1.          .015        .106        .094        .003
  2.          .074        .532        .470        .016
  3.          .149       1.063        .940        .032
  4.          .298       2.127       1.880        .056
  5.          .446       3.190       1.349        .033
  6.          .521       3.722        .574        .013
  7.          .595       4.253        .328        .007
  8.          .669       4.785        .092        .002
  9.          .744       5.317        .051        .001
 10.          .893       6.380        .015        .000
 11.         1.190       8.506        .004        .000
 12.         1.488       8.613        .002        .000

         FALL PUPAE

         FOR DOUGLAS FIR 30.00% NEW FOLIAGE

LASS             I          II         III          IV
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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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Fairbanks, Alaska
Juneau, Alaska
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